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# Science, technology, innovation, theory and evidence: the new institutionality in Colombia

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**Abstract**
It is widely recognized that the design and application of suitable and robust science, technology and innovation (STI) policies and appropriate STI institutions promote development, economic growth and competitiveness in the long run. This paper analyses the dynamics of STI in Colombia over the 1995–2019 period to determine its relationship with its most important determinants and its collateral relationship with economic growth as an input affecting different issues; this work takes into account the creation of the new ministry of science, technology and innovation (MSTI) and uses different time series techniques. According to the analysis, a positive relationship exists between investments in research and development, STI activities, and the independence and transparency of STI management by the new MSTI, which could generate higher productivity, technological change, economic growth and development. The results of the models also demonstrate the long-run relationship and short-run dynamics related to STI investment and research results and the importance of transparency and independence. It is important to establish adequate STI governance and allow new ministries to play an important role to achieve a society based on knowledge that produces relevant research, technology and innovation based on the needs and resources of the country.

**Keywords** Institutions · Science · Technology · Innovation policies · Times series · Colombia

## 1 Introduction

The research and development (R&D) and innovation policies adopted for different developed countries have a demonstrated relationship with economic growth, development and competitiveness (Griffith et al. 2004). For different countries, science, technology and innovation (STI) have become a decisive factor by changing the production function. New

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technologies, innovations and investments in knowledge generation have generated high productivity, efficiency and competitiveness, which are key factors in economic growth and development and generate wealth and welfare in society (Liik et al. 2014; Bilbao-Osorio and Rodriguez-Pose 2004).

STI are considered important factors for promoting competitiveness and achieving growth, especially in developed countries, as observed by Romer (1986, 1990), who determined that growth occurs through the accumulation of knowledge. Growth theories in recent decades have acknowledged the importance of technological change and identified the knowledge economy as a source of economic growth because it promotes organizational change, collaboration, knowledge sharing, improved connectivity and networks, the application of standards, and new technologies, among other benefits (e.g. Grossman and Helpman 1991; Todaro 1997; Crosby 2000; Zalewski and Skawinska 2009).

STI policies should be based on an analysis of the features of knowledge transfer, technological change and innovation processes, including the following (Aghion et al. 2009): (i) the cumulative processes over time leading to feedback, knowledge accumulation and lock-in effects; (ii) the multidirectional links at the same point in time between the stages of new knowledge, its application, technological change and the implementation of innovation; (iii) development patterns and processes for diffusing and appropriating new technologies and innovations; (iv) dependence on new knowledge, technological change and the absorption and application of information through learning; and (v) she systemic and interdependent features of the technological change and innovation process. These elements are key to understanding how STI supports countries' economic growth and development.

An institutional framework is fundamental to achieving results from STI, as it is the source of plans and strategies for economic growth, sustainable development, and social inclusion. Moreover, investments in R&D and science, technology and innovation activities (STIA) identify new technologies and innovations that will support growth and development and where new infrastructure is necessary, such as digital connectivity and broadband communication networks (Álvarez 2016; Hall et al. 2013). In parallel, different interest groups must engage in strong cooperation in research, transfer, innovation diffusion, knowledge generation, human resource development, public awareness, and dialogue on STI. In this context, the government can play an important role by stimulating new demand through strategies and programmes based on knowledge and public investment that will strengthen the STI infrastructure (G7 Academies 2017, Cotte 2018).

These elements motivate this research, which analyses a newly created institution in Colombia, the Ministry of Science, Technology and Innovation (MSTI), with the goal of understanding how to improve or generate new STI infrastructure with limited resources to promote STI in a developing country. The aim is to generate new strategies to valorise knowledge as a fundamental element for economic growth and development, taking into account that evidence regarding these issues in emerging economies is relatively scarce. Some studies have analysed topics related to STI, value creation, information and communications technology (ICT), capacities, and human resources, among others, in the Latin American context [e.g., IDB (2010), Crespi et al. (2014), in Latin America and the Caribbean; Benavente (2006) and Álvarez (2016), in Chile; Aboal and Tacsir (2015), in Uruguay; Commander et al. (2011), and Rezende et al. (2017), in Brazil]. The findings of these researchers are consistent in recognizing the importance of STI to promoting productivity, competitiveness, and development when supported by adequate policies.

The aim of this paper is to apply empirical and econometric strategies to analyse how new institutions in Colombia depend on investments in R&D and STIA and to identify those variables that promote STI and guarantee the independence of innovators and

transparency to investors. The new MSTI should be based on the market and the public, which relates to two theories: the positive theory of state, which analyses how the state performs, what it is similar to and what it does in the economic system and in society, and the normative theory of state, which refers to the study of how the state should exercise its ability to direct activity and improve equity and efficiency. The modern theory of the public sector includes three elements: welfare economics, which seeks to improve human welfare and social conditions, primarily through the optimal distribution of wealth; the theory of public election, which studies the behaviour around taxes and public spending; and public finances, which analyses behaviour related to investment and the principles of state expenditures and state revenues. These theories are important to determine the key elements of the new institution and the political theory that it will follow.

This study provides novel evidence for a developing country, Colombia, on the importance of investing in an institution and in STI through the creation of MSTI. The research questions that guide this study are as follows: (i) What are the effects of implementing an MSTI for a developing country such as Colombia? (ii) What elements could affect the new MSTI, taking into account the trends in STI in Colombia?

In the development of this research, we conducted a literature review (Sect. 2); in the subsequent section, the different Colombian Ministries and Colciencias, as governing bodies of STI policies, are analysed. The methods and data used in this study are presented in Sect. 4. The empirical results are discussed in Sect. 5 together with the robustness check. The conclusions are presented in Sect. 6.

## 2 Literature review

STI play a critical role in constructing and supporting national competitiveness, driving solutions to global challenges and realizing sustainable development, while information and communication technologies promote and empower the development of STI (United Nations 2016). Public institutions, especially policy makers, play an important role in developing appropriate STI policies to promote economic growth and create a knowledge-based society.

The economic theory related to STI identifies the following factors: (i) STI drives growth through savings and capital accumulation (Schumpeter 1939; Hulten and Isaksson 2007); (ii) economic development implies the restructuring and relocation of resources based on new STI advances that replace old processes (Schumpeter 1939; Caballero and Hammour 2000; Datta et al. 2013); (iii) STI efficiency (how capable a society is in using STI to generate new products, services and processes) takes precedence over allocative efficiency (the optimal production and distribution of goods and services in response to market demand) given adequate policies and institutions to control market failures (Freeman 1987; Woolthuis et al, 2005); (iv) STI are risk processes because they are developed based on trial and error attempts and limited information, so R&D requires particular supporting instruments to achieve successful results (Haragadon, 2011); (v) STI must interact with and require human capital, business culture, regulations, public institutions, networks, etc., which are all fundamental to achieving a knowledge society (Metcalfe 1995; Trott 2011). These elements indicate the importance of a national STI system led by adequate institutions and governance to achieving effective economic growth and development based on knowledge, technology and innovation.

To achieve economic growth based on STI, an adequate institutional framework is necessary to coordinate the effort to generate new policies and new institutional systems (ECLAC 2016): (i) countries design policies that can be applied through institutional resources such as the ministry responsible for this topic; (ii) policies must be viewed from a functional perspective, integrating and facilitating interaction with the business and productive sector, incorporating the regional dimension, facilitating articulation among different organizations (universities, research centres, among others) and different sectors, diffusing knowledge and forming linkages; (iii) The business dynamic requires the application of policies to protect competition shared with institutions aimed at strengthening good corporate governance practices and guaranteeing the interests of domestic and external investors to enhance the generation and transfer of technology and knowledge.

Developing and applying a successful STI policy implies coordinated management with a public institution, such as MSTI, that leads through explicit and implicit policies. Explicit policies can address technology, innovation parks, research centres, business incubators, and the transfer of technology through foreign direct investment or trade. In contrast, implicit policies reflect the impacts and effects on the development of STI capabilities and the relationships with the economy (e.g., trade policies, public procurement, taxation, investments). The challenge in developing these policies is the requirement to balance both market and systemic failures and to mix horizontal (education, finance, or knowledge dissemination and application) and vertical policies (support the use of STI among the productive sector). These elements promote economic growth when coordinated with STI policies, overall development strategy, industrial and trade policy, environmental standards, and education policy, among others, and strong institutional framework from the central government (UNCTAD 2019; Bernanke 2011).

These elements suggest the importance of knowledge to the generation of wealth in countries (Cavalcanti 2001). Taking into account the transformation and return in the form of patents, products, scientific research, certifications, new businesses, entrepreneurships, and technologies, among others, allows us to guarantee increases in productivity, innovation, and competitive advantage that lead to economic, intellectual and social growth and development (Barney and Hesterly 2006; Rezende et al. 2017). Due to the importance of STI, this study seeks to analyse in a developing country the importance of a new MSTI to promoting development through knowledge creation and the importance of independence and transparency for this institution given the adequate allocation of investment to generating new STI products and services.

Considering gaps in the previous literature, our analysis sheds light on the importance of adequate institutions and policies in promoting STI and the relevance of investments in R&D and STIA. Further, it suggests different elements and inputs that could be taken into account by the new MSTI to guarantee effective decisions and the importance of STI to promoting development and economic growth.

## 3 Analysis of Colombian institutions through the ministries

Colombia is a country characterized by a representative, republican, and democratic form of government, where executive power dominates the other branches (legislative power and judicial power), and ministers are important figures in charge of ministries who hold positions that are simultaneously administrative and political. The main

function of ministers is to set national policy in all fields of government activity and to issue regulations and specific laws.

Before the MSTI was created, in Colombia, STI was managed by a department of science, technology and innovation denominated Colciencias through Law 1286 of 2009. This entity was responsible for promoting STI policies that encouraged the production of knowledge and the construction of STI capabilities and that facilitated the circulation and uses of such capabilities and knowledge for the integral development and welfare of Colombian society. Moreover, Colciencias coordinated the national system of science, technology, and innovation (SNCTI), defined strategic programmes for the development of the country, and outlined all activities involved in the promotion of research and innovation (OCyT et al. 2013).

Currently, the country has 16 ministries that can be classified based on their annual budget to show their importance to the government and to the focalization of resources for generating economic growth and development. The ministries were classified by budget ranges taking into account the operating and investment expenses of each ministry through k-means clustering, as proposed by MacQueen (1967). From a sample ($w_1$, $w_2$…, $w_n$), each observation is a d-dimensional real vector, and the purpose of k-means clustering is to partition the n observations into k sets (k\n) $Y = \{Y_1, Y_2\ldots, Y_k\}$ to minimize the within-cluster sum of squares (see Eq. 1).

$$\arg mins = \sum_{i=1}^{K} \sum_{w_j \in Y_i} \| w_j - \mu_i \|^2 \tag{1}$$

Data were calculated in constant 2015 values for the budgets and validated of each year. For those ministries with a high budget, the range is between a minimum value of $4.49^{e+12}$ and a maximum value of $3.34^{e+13}$. For the ministries with a medium-sized budget, the minimum value is 0, and the maximum value is $1.57^{e+13}$. For ministries with a low budget, the minimum value is $6.98^{e+10}$ and the maximum value is $5.03^{e+12}$, and those with the lowest budget have a range between a minimum value of 92,721 and a maximum value of $3.90^{e+11}$. Table 1 shows the classification of Colombian ministries by budget, including Colciencias as the administrative agency for STI, and Fig. 1 shows ministry budgets, classified from high to low, in comparison with Colciencias.

Examining those ministries with a high budget shows that during the period of study, the Ministry of Education increased its budget consistently, and the Ministry of Work also shows an upward behaviour, especially in 2014, due to different implemented programmes, such as public employment services, older Colombia, and retirement systems. The Ministry of the Treasury and Public Credit shows a decrease in the last period due to changes in the management and distribution of resources.

For ministries with medium-sized budgets, the Ministry of National Defence, the Ministry of Housing, City and Territory and the Ministry of Mines and Energy show similar behaviour over the last decade (in this latter ministry between 2008 and 2010, there was an increase in investments in infrastructure based on exploration in oil and the new electrification process). The ministry of health and social protection shows a different trend including a decrease and an increase. In recent years, this ministry has increased investments to obtain improvements in coverage and infrastructure, new programmes to improve quality and prevention and specialized equipment.

The ministries with the lowest budgets show a similar trend over the last decade. The ministry of justice and law and the ministry of information and communication

**Table 1** Budget classification of Colombian ministries. *Source*: Authors, based on the General Budget of the Nation produced by the Ministry of Finance and Public Credit, the DNP (National Planning Department), and the General Comptroller of the Republic

| Ministries of Colombia | Budget classification |
|---|---|
| Ministry of National Education | High |
| Ministry of Work | High |
| Ministry of Treasure and Public Credit | High |
| Ministry of Health and Social Protection | Middle |
| Ministry of Mines and Energy | Middle |
| Ministry of National Defence | Middle |
| Ministry of Housing, City and Territory | Middle |
| Ministry of Agriculture and Rural Development | Low |
| Ministry of Interior | Low |
| Ministry of Commerce, Industry and Tourism | Low |
| Ministry of Foreign Relations | Low |
| Ministry of Culture | Low |
| Ministry of Environment and Sustainable Development | Low |
| Ministry of Transportation | Low |
| Ministry of Justice and Law | Lower |
| Ministry of Information and Communication Technologies | Lower |
| Colciencias | Lower |

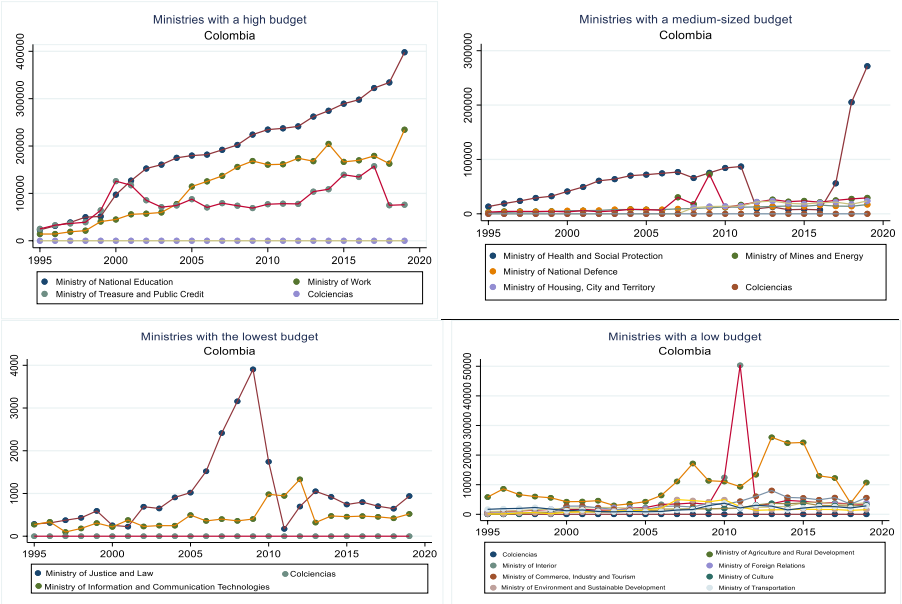


**Fig. 1** Trends in ministry budgets according to their classification, 2000–2018. *Source*: The General Budget of the Nation produced by the Ministry of Finance and Public Credit, the DNP (National Planning Department), and the General Comptroller of the Republic.

technologies decreased their budgets beginning in the last decade due to new government priorities and the requirements of other priority sectors.

Ministries with low budgets show similar trends except for the ministry of the interior and the ministry of agriculture and rural development, which had increases and decreases according to government requirements, institutional strengthening, and special programmes to enhance agricultural activities, among others. These dynamics in the Colombian ministries show different trends according to the requirements and programmes of governments. However, STI investments were not considered key investments for promoting growth and development in Colombia, as evidenced by a budget that improved based on the designation of royalties between 2012 and 2015 but saw an investment below 1% of gross domestic product during the decade and never exceeded the budget of other ministries.

These trends also indicate that colciencias has maintained the lowest budget of all the ministries; in fact, its budget is too low to allow it to be considered a ministry. In recent years, the trends in budget and budgetary implementation have decreased (see Fig. 2). The MSTI requires more resources to achieve significant STI through R&D, innovation, scientific and technological training and education, scientific management and STI support, as these will be fundamental for the successful management, policy development and governance of the new MSTI, taking into account the expectations of different stakeholders.

## 4 Methods and data

This study follows STI theories to evaluate the effects of the new institution in Colombia based on the objectives of Law 1951 of 2019. The paper follows these stages: (i) simulations for independence and transparency; (ii) estimations of two proposed models and application of tests to determine stationarity. These stages are explained in the following:

### 4.1 Simulations for independence and transparency

To determine the independent variable, a perception survey was conducted regarding the implementation of the MSTI in Colombia. This survey was developed by the Colombian

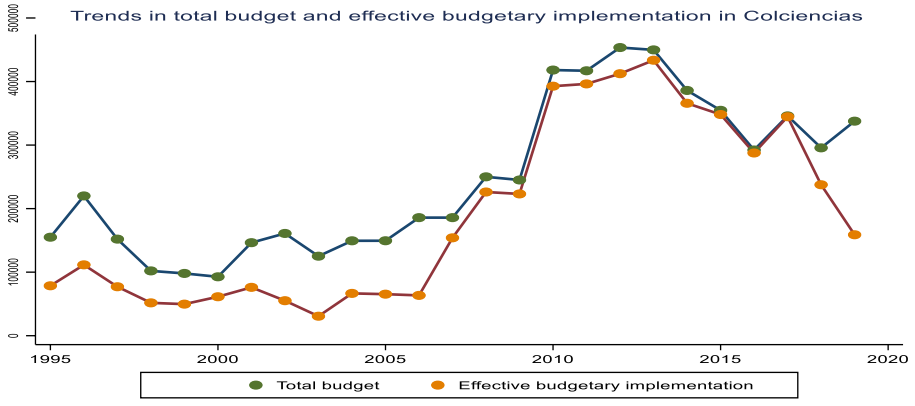


**Fig. 2** Trends in total budget and effective budgetary implementation in Colciencias, 1995–2018. *Source*: Planning office of Colciencias, Ministry of Finance and Public Credit, DANE

Observatory of Science and Technology (OCyT) in 2019 to understand opinions about the proposed institutional change for the National System of Science, Technology and Innovation. The survey was distributed to different stakeholders who were directly and indirectly related to science and technology activities, including researchers, universities, entrepreneurs, policy makers, administrative personnel, research centres and members of the general public interested in STI topics (Pardo Martínez et al. 2019).

Table 2 shows the main variables used to build and analyse the political independence of the new MSTI. The main variables related to the proper management of the MSTI were determined based on the international literature, including (i) the management of the entity, (ii) STI policy formulation, (iii) the entity's objectives, and (iv) government restrictions on resource allocation.

An important point of analysis is the political independence of the new MSTI, which must operate with a high level of autonomy and whose mandate should be to encourage everything related to STIAs in coordination with general economic policy. The new MSTI must design its policies from a long-term perspective that is independent of the political cycle.

To construct the transparency variable, the perception survey data was taken from a module on the perception of transparency factors as applied to stakeholders. These are mainly related to variables capturing political, economic, and procedural factors or related to the operation of the entity, specifically its administrative, managerial and financial methods of operation. Table 3 lists the main variables used to build the survey and analyse the transparency of the new MSTI.

With respect to transparency, it is important that the new MSTI achieve effective management that enables society to understand the STI policy, its main results and the investments made to guarantee the importance and support of STI in different processes. Table 3 shows the features for analysing transparency.

**Table 2** Factors that determine the political independence of the new MSTI

| Factor | Features |
|---|---|
| The management of the entity | The length of the term of service of the director<br>Who appoints the director<br>Reasons for leaving office<br>Whether the director can have other functions in the government |
| The formulation of STI policy | Who formulates STI policy<br>Who has the final say in resolving conflicts in terms of STI policy<br>The role of the government budget process |
| The objectives of the entity | Stability in STI spending |
| Government restrictions on the allocation of resources | Tax rule<br>Deficit or surplus<br>Fiscal sustainability |

**Table 3** Factors that determine the transparency of the new MSTI

| Factors | Features |
|---|---|
| Political factors | There is a political objective<br>Type of decisions |
| Economic factors | The entity has economic interests<br>The entity has interest groups it privileges<br>The allocation of resources is equitable<br>The allocation of resources is efficient<br>The allocation of resources is transparent |
| Procedures | The entity has adequate procedures<br>The entity has clear, adequate and transparent processes |
| Performance | The entity prides itself on being a technical body<br>The entity prides itself on being a political body<br>The entity has clear and adequate programmes<br>The entity has clear plans that are consistent with its mission<br>The mission of the entity is consistent with current technical or social developments<br>The vision of the entity adjusts to modern advances<br>The strategic planning of the entity adjusts with that of its peers |
| Operability | The entity has an adequate budget<br>The entity has adequate budgetary execution |

To conduct the different simulations for the variables of independence and transparency, the methodology used by Pindick and Rubinfeld (1997) is followed. Historical simulation is used for a known sample period and applied in predictive simulation. Next, to obtain robust results, comparisons are made between the predictions and the actual data based on the data structure; the comparisons adopt the following general structure (Eqs. 2 and 3).

$$x_1, x_2, \ldots x_t, \ldots x_T \quad \text{realizations} \tag{2}$$

$$\hat{x}_1, \hat{x}_2, \ldots \hat{x}_t, \ldots \hat{x}_T \quad \text{predictions} \tag{3}$$

To minimize possible systematic errors in prediction, the different simulations take the form determined by the following expression (Eq. 4),

$$\hat{x}_t = \alpha + \beta x_t + e_t; \quad t = 1, 2, \ldots, T \tag{4}$$

## 4.2 Estimations of the two proposed models and application of the tests to determine stationarity

To analyse the main variables and the factors that affect the management and operation of new MSTI, this study formulates its analysis according to the following classifications: indicators of structural change in STI, indicators of human capital, indicators of knowledge creation and institutional indicators related to independence and transparency. Two models are used to describe the behaviour of STIAs and R&D.

The analysis is performed for the 1995–2019 period, for which there are available data in Colombia on STI issues. The data used in this study are as follows: the data on investments in STIA and R&D investments are taken from the World Bank and Ricyt following the requirements of the Frascati manual 2015 developed by the OECD and are expressed in 2015 Colombian pesos, Cotte and Andrade (2018, 2019) and Cotte et al. (2019); the data on the number of master's and PhD programmes come from the national system of information of higher education; the number of recognized research groups come from the scienti platform of Colciencias; the number of scientific papers published and citations are taken from the WoS, Scopus, and SciELO; the data on patents and trademarks were obtained from the national office of the industry and commerce superintendence (SIC); the number of software registrations were obtained from the national copyright office; and public expenditure on education was obtained from the General Budget of the Nation produced by the Ministry of Finance and Public Credit, and the variables on independence and transparency were taken from the survey performed for this study.

The two models proposed in this study show the generation of knowledge through knowledge spillover. They indicate that researchers and scientists are now the key creators of R&D, achieving sustained economic growth when there is sufficient investment in the sector; therefore, the factors used attempt to capture productivity (Acemoglu 2009). Moreover, the two models follow the technological change model proposed initially by Romer (1990), the growth model proposed by Rebelo (1991), and studies developed by Křistkova (2012) in the context of the Czech Republic and Kim et al. (2019) to analyse South Korea's R&D investments.

The findings of these studies demonstrated that R&D resources are restricted, and it is necessary to determine the degree of contribution of R&D determinants to economic growth and development by estimating R&D stock based on the knowledge production function. In this context, this study proposes and follows these models and theoretical elements to analyse the relationship between STI investments (classified as STIA and R&D), resources and knowledge results in Colombia as input, analysing the role of new institutions based on MSTI. The research of Enders (2014) on the application of small time series on stationarity is followed.

### 4.3 Technological and innovation activities (STIA) model

This model includes the following activities: STI investments, innovation, support for scientific and technological education and training, management and other related activities, and STI support. Equation (5) is as follows:

$$\mathrm{STIA}_t = \alpha_i + \beta_i X + \xi_t \tag{5}$$

where STIAs are the different technological and innovation activities, α is the constant, X is a variable set that represents the indicators of structural change, human capital for STI and knowledge generation, and ξ is the error term.

To determine the reliability and robustness of the results, different tests in levels and differences are applied to determine the seasonality of the series with the Dickey–Fuller and Phillip–Perron tests.

### 4.4 Research and development (R&D) model

The second model also includes a structured equation system to describe R&D behaviour. Equation (6) is as follows:

$$R\&D_t = \gamma_i + \Omega_i X + \mu_t \quad (6)$$

where R&D is Research & Development investments, γ is the constant, Ω is the estimated coefficient, X is a set of variables that represent structural change, human capital in STI and knowledge generation, and μ is the error term.

To determine the reliability and robustness of the results, the Dickey–Fuller and Phillip–Perron tests are applied to levels and differences to determine data stationarity.

## 5 Results and discussion

Following the methods and models proposed in this study, this section explains the results of the different simulations to determine the dynamics in STI in the context of the creation of a new MSTI, which is key to improving development outcomes. The main function of the MSTI is to work in partnership with science and technology institutions, organizations, and other innovative enterprises to research, test, evaluate and scale solutions (USAID 2017).

### 5.1 Results of simulations for independence

The political independence of the MSTI is a fundamental pillar required to obtain the best results and refers to several aspects, among which the following must be present: (a) The entity must be directed by a policymaker who is knowledgeable about STI, the term of office must be a relatively long period, and appointment must be made by a board of experts on the subject; (b) the technical aspects and the formulation of STI policy should be evidence-based and attain the expected results; (c) The objectives of the entity and the execution of its activities must be clear and transparent; and (d) government restrictions on the allocation of resources and their efficient allocation are central to the final execution of activities. These results concur with UNCTAD (2019) and OECD (2017a, b), which determined that for an enterprise to be adequate, the policy debate and policy-making process require an independent evaluation and decision making by expert teams or entities that can detect early warnings and make relevant decisions.

With these criteria, a series of simulations were performed, and the results regarding the independence of the MSTI are shown in Table 4. It can be seen that the results considerably improve if the entity has the fundamental characteristic of independent decision making; without reform, the average is 0.79, and with reform, the results are 0.94, showing a substantial improvement in the results and operation of the new entity. Similar results were obtained by Mukhopadhyay (2014) in the Indian context, showing the importance of an ecosystem that addresses the national priority for inclusive and accelerated growth. In such an ecosystem, policy makers and the government promote different programmes and instruments and provide independent and efficient investments to achieve a symbiotic relationship between the STI system and socioeconomic areas. STI then benefits its

**Table 4** Results of the simulations of independence

| Variable | Observations | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Without reform | | | | | |
| Indicator of independence of MSTI | 51 | 0.795921 | 0.0186229 | 0.7795 | 0.8295 |
| With reform | | | | | |
| Indicator of independence of MSTI | 51 | 0.9406 | 0.04215 | 0.8723 | 0.9769 |

Simulations: Author's calculations from the transparency and independence survey

stakeholders in society, while innovation promotes inclusive growth and ensures the access to, availability of and affordability of different solutions to improve welfare. This perspective can allow the acceleration of science-led solutions for rapid, sustainable and inclusive growth.

### 5.2 Results of simulations for transparency

The transparency of the institution is another essential, strategic criterion for the achievement of optimal results with scarce resources. Transparency takes into account several aspects: (a) the efficient allocation of resources, their relevance to STI topics and knowledge generation should be the most important factors considered when allocating scarce resources; (b) processes should be characterized by agility, efficiency and transparency at all levels; (c) the operation of the entity requires highly trained human resources and staff who are knowledgeable about STI; and (d) technologies, systematization and effectiveness in execution are essential criteria for the proper operation of the institution and its external agents. Transparency is important in STI governance because it allows the public to understand the overall system, evaluate a given outcome, view how publicly funded resources are used in STI and understand what benefits are obtained (EPRS 2019).

Under these premises, a series of simulations were carried out for the transparency of the MSTI, and the results are shown in Table 5. The simulations show that with the implementation of the transparency criteria, substantial improvements from 0.4 to 0.9 can be achieved if the entity's transparency is improved over time. According to the OECD (2002, 2017a, b) the main benefits of transparency regarding budgets sourced from public funds or resources are as follows: (i) accountability allows for the determination of how to use public funds and ensures accountability, which promotes effectiveness and efficiency because it accounts for the allocation and priorities of national stakeholders; (ii) integrity

**Table 5** Results for the simulations of transparency

| Variable | Observations | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Without reform | | | | | |
| Indicator of transparency of MSTI | 51 | 0.444 | 0.0187 | 0.4259 | 0.4785 |
| With reform | | | | | |
| Indicator of transparency of MSTI | 51 | 0.9086 | 0.01062 | 0.8846 | 0.9201 |

Simulations: Author's calculations from the transparency and independence survey

is encouraged to prevent corruption and maintain high standards of responsibility in the use of public funds; (iii) inclusiveness is promoted because budget decisions affect all of society, and transparency involves an informed and inclusive debate about budget policy impacts; (iv) an open and transparent budget process fosters trust among citizens because they can see how public money is used; and (v) quality is implied by transparent and inclusive budgeting support because of the associated fiscal results and the reactive, impactful and unbiased public policies. These elements contribute to the new MSTI's adequate use of resources and consideration of the social impact based on knowledge, new technology and innovation.

### 5.3 Results of test for data stationarity

A series of correlational exercises were conducted based on several classifications for the different variables: structural change indicators in STI, human capital indicators, knowledge creation indicators and institutional indicators of independence and transparency. The Dickey-Fuller and Phillip-Perron tests were performed both on levels and on differences to determine the stationarity of the series. To test the order of integration of the variables, we used the standard unit root tests, namely, the augmented Dickey-Fuller and the Phillips-Perron tests. The results of the unit root tests, reported in Table 6, indicate that the variables meet the conditions of stationarity in the series.

### 5.4 Estimation results

The first model (see Table 7) has investments in STIAs as the dependent variable, and the results show that higher investments in STIAs can generate higher transparency and independence in the new institution. Moreover, investments in STIAs related to human capital promote higher numbers of graduates in the national PhD programmes and more scholarships, which is consistent with the investment expenditures in Colciencias, taking into account that the majority of the budget of the entity is dedicated to higher level training through PhD and master's programmes.

Another factor analysed in this model is research results. The results indicate that higher investments in STIAs have a positive and significant effect on the numbers of research groups recognized by Colciencias, scientific papers published, total national patents granted, trademarks, software registration, and Scopus citations and on public expenditure in education as a percentage of GDP. These findings demonstrate the importance of new institutions as a key element to strengthen human capital and research results in Colombia. These results show the importance of STI in supporting poverty eradication through education and sustainable development through the development of new clean technologies and innovations. STI policies should adopt a holistic framework and strategically connect the integral parts of their national development policies and plans to policies in other sectors, such as education, industry, and health. Sustainable development and socioeconomic well-being can be obtained by addressing specific STI governance issues, such as funding mechanisms, national STI commissions, STI laws and other STI policy instruments (UNESCO 2017).

The second model (see Table 8) was analysed using investments in R&D as the independent variable. The results show that higher investments in R&D generate higher transparency in the new institution, indicating the importance of formulating a new mode of governance to achieve higher impact from STI in Colombia (see Table 8). The variables

**Table 6** Results for stationarity—unit root test

| Parameter | Dickey-Fuller Test | Phillip-Perron Test | Parameter | Dickey-Fuller Test | Phillip-Perron Test |
|---|---|---|---|---|---|
| Science, technology and innovation activities (STIA) | −4.085 (0.001) | −4.095 (0.001) | Software registration | −3.438 (0.009) | −3.447 (0.009) |
| National PhD programmes | −2.837 (0.050) | −2.813 (0.050) | Independence policy indicator for the entity without reform | −3.875 (0.002) | −3.875 (0.002) |
| Total scholarships | −6.533 (0.000) | −6.493 (0.000) | Independence policy indicator for the entity with reform | −5.087 (0.000) | −5.419 (0.000) |
| Number of research groups recognized by Colciencias | −3.881 (0.002) | −3.875 (0.002) | Transparency indicator for the entity without reform | −3.917 (0.001) | −3.912 (0.001) |
| Scientific papers published | −4.542 (0.000) | −4.582 (0.000) | Transparency indicator for the entity with reform | −4.528 (0.000) | −4.608 (0.000) |
| Scopus citations | −3.337 (0.0133) | −3.353 (0.0127) | Research and development | −2.857 (0.050) | −2.834 (0.050) |
| Total national patents granted | −6.282 (0.000) | −6.451 (0.000) | Public expenditure on education as % of GDP | −4.748 (0.000) | −4.856 (0.000) |
| Total international patents granted | −6.013 (0.000) | −6.144 (0.000) | Investment expenditures of Colciencias | −5.100 (0.000) | −4.969 (0.000) |
| Trademarks | −5.431 (0.0000) | −5.631 (0.0000) | | | |
| *P* value | *P* value ≤ 0.05 | *P* value ≤ 0.05 | P-value | *P* value ≤ 0.05 | *P* value ≤ 0.05 |

**Table 7** Model 1: dependent variable is investments in science, technology and innovation activities (STIAs)

| Parameter | Model [1] | Model [2] | Model [3] | Model [4] | Model [5] | Model [6] | Model [7] | Model [8] | Model [9] | Model [10] | Model [11] | Model [12] | Model [13] | Model [13] | Model [14] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Constant | 14.395*** (0.082) | 14.488*** (0.072) | 13.823*** (0.187) | 14.079*** (0.135) | 15.906*** (0.124) | 11.364*** (0.957) | 14.464*** (0.102) | 13.869*** (0.395) | 13.154*** (0.262) | 14.093*** (0.112) | 5.383*** (1.473) | 19.714*** (17.073) | 15.006 (0.111) | 8.265*** (1.018) | 19.483*** (1.234) |
| National PhD pro-grammes | 0.0021*** (0.000) | | | | | | | | | | | | | | |
| Total schol-arships | | 0.0001*** (0.000) | | | | | | | | | | | | | |
| Number of research groups recognized by Col-ciencias | | | 0.0003*** (0.000) | | | | | | | | | | | | |
| Scientific papers published | | | | 0.000*** (0.000) | | | | | | | | | | | |
| Scopus cita-tions | | | | | 0.073*** (0.008) | | | | | | | | | | |
| Public expendi-ture on education as % of GDP | | | | | | 0.836*** (0.222) | | | | | | | | | |
| Total national patents granted | | | | | | | 0.002*** (0.000) | | | | | | | | |

**Table 7** (continued)

| Parameter | Model [1] | Model [2] | Model [3] | Model [4] | Model [5] | Model [6] | Model [7] | Model [8] | Model [9] | Model [10] | Model [11] | Model [12] | Model [13] | Model [14] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total international patents granted | | | | | | | | 0.000*** (0.000) | | | | | | |
| Trademarks | | | | | | | | | 0.000*** (0.000) | | | | | |
| Software registration | | | | | | | | | | 0.000*** (0.000) | | | | |
| Investment expenditures of Colciencias | | | | | | | | | | | 0.776*** (0.119) | | | |
| Independence policy indicator for entity without reform | | | | | | | | | | | | -6.082 (21.828) | | |
| Independence policy indicator for entity with reform | | | | | | | | | | | | | 60.018 (104.8) | |

**Table 7** (continued)

| Parameter | Model [1] | Model [2] | Model [3] | Model [4] | Model [5] | Model [6] | Model [7] | Model [8] | Model [9] | Model [10] | Model [11] | Model [12] | Model [13] | Model [13] | Model [14] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transparency indicator for entity without reform | | | | | | | | | | | | | | -8.262*** (1.255) | |
| Transparency indicator for entity with reform | | | | | | | | | | | | | | | 50.266*** (13.673) |
| Prob > F | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.005 | 0.000 | 0.001 |
| R-squared | 0.48 | 0.47 | 0.44 | 0.47 | 0.46 | 0.43 | 0.47 | 0.48 | 0.44 | 0.48 | 0.47 | 0.45 | 0.42 | 0.47 | 0.44 |

Notes: Figures in parentheses are the standard errors

*** Significant at the 1 percent level, ** Significant at the 5 percent level and * Significant at the 10 percent level

**Table 8** Model 2: dependent variable is investments in research and development (R&D)

| Parameter | Model [1] | Model [2] | Model [3] | Model [4] | Model [5] | Model [6] | Model [7] | Model [8] | Model [9] | Model [10] | Model [11] | Model [12] | Model [13] | Model [14] | Model [15] | Model [16] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Constant | −0.550*** (0.074) | −0.177*** (0.035) | −0.143*** (0.038) | −0.786*** (0.189) | −0.930*** (0.125) | −0.277*** (0.046) | −0.437*** (0.167) | −0.167*** (0.042) | −0.369 (0.120) | −1.711*** (0.368) | −0.670*** (0.085) | −0.891*** (0.214) | −0.102 (0.518) | −1.604*** (0.068) | −0.586*** (0.140) | 0.719*** (0.162) |
| National master's programmes | 0.085*** (0.008) | | | | | | | | | | | | | | | |
| National PhD programmes | | 0.071*** (0.006) | | | | | | | | | | | | | | |
| Total scholarships | | | 0.047*** (0.005) | | | | | | | | | | | | | |
| Number of research groups recognized by Colciencias | | | | 0.121*** (0.023) | | | | | | | | | | | | |
| Scientific papers published | | | | | 0.127*** (0.014) | | | | | | | | | | | |
| WoS SciELO citations | | | | | | 0.062*** (0.006) | | | | | | | | | | |
| Public expenditure on education as % of GDP | | | | | | | 0.440*** (0.115) | | | | | | | | | |

**Table 8** (continued)

| Parameter | Model [1] | Model [2] | Model [3] | Model [4] | Model [5] | Model [6] | Model [7] | Model [8] | Model [9] | Model [10] | Model [11] | Model [12] | Model [13] | Model [14] | Model [15] | Model [16] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total national patents granted | | | | | | | | 0.072*** (0.008) | | | | | | | | |
| Total international patents granted | | | | | | | | | 0.250** (0.034) | | | | | | | |
| Trademarks | | | | | | | | | | 0.190*** (0.036) | | | | | | |
| Software registration | | | | | | | | | | | 0.117*** (0.011) | | | | | |
| Investment expenditures of Colciencias | | | | | | | | | | | | 0.088*** (0.017) | | | | |
| Independence policy indicator for entity without reform | | | | | | | | | | | | | −1.243 (2.110) | | | |

**Table 8** (continued)

| Parameter | Model [1] | Model [2] | Model [3] | Model [4] | Model [5] | Model [6] | Model [7] | Model [8] | Model [9] | Model [10] | Model [11] | Model [12] | Model [13] | Model [14] | Model [15] | Model [16] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Independence policy indicator for entity with reform | | | | | | | | | | | | | | 35.284 (63.95) | | |
| Transparency indicator for entity without reform | | | | | | | | | | | | | | | −0.975*** (0.173) | |
| Transparency indicator for entity with reform | | | | | | | | | | | | | | | | 5.732*** (1.797) |
| Prob > F | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.001 | 0.000 | 0.003 | 0.000 | 0.000 | 0.000 | 0.05 | 0.05 | 0.000 | 0.000 |
| R-squared | 0.48 | 0.48 | 0.48 | 0.46 | 0.48 | 0.48 | 0.46 | 0.48 | 0.42 | 0.46 | 0.48 | 0.46 | 0.42 | 0.41 | 0.46 | 0.43 |

Notes: Figures in parentheses are the standard errors

*** Significant at the 1 percent level, ** Significant at the 5 percent level and * Significant at the 10 percent level

related to human resources indicate a positive and significant effect on national PhD and master's programmes, total scholarships, number of research groups recognized by Colciencias, public expenditure on education as a percentage of GDP and expenditure on investments by Colciencias. These results demonstrate the importance of achieving transparency in the new institution and continuing to strengthen infrastructure capacity to achieve a knowledge-based society.

The results show that investments in R&D have a positive and significant effect on the numbers of scientific papers published, total international patents granted, trademarks and software registrations, indicating the importance of investments in R&D and adequate governance for increasing research results.

The results of both models indicate the importance of adequate STI policies and new STI institutions to achieve better results in the generation of knowledge and to promote innovation and new technologies in the productive sector. According to the European Commission (2015), STI policies should be analysed considering the following aspects: (i) whether they target the generation and transfer of new technologies and innovations to drive economic growth and sustainable development; (ii) whether they promote the creation of new technologies that encourage research and support innovation; (iii) whether they structure adequate regulatory and governance frameworks for disseminating technologies, especially for micro, small and medium-sized enterprises, and whether they promote industrial diversification and encourage higher value-added commodities; (iv) whether they promote social innovation to support welfare and sustainable livelihoods; (v) whether they enhance knowledge sharing and cooperation between stakeholders, such as governments, firms, academia and civil society, according to the four-helix model; (vi) whether they increase the finances and policies targeting research and technological development with strategies of open access to follow the research process, investments and results; (vii) whether they strengthen international cooperation and STI collaboration to achieve mutual benefits and pertinent knowledge in various regions; and (viii) whether they prioritize areas such as health, food security, value added for commodities and agricultural productive capacity. These elements are important for allowing policy makers and decision makers to succeed and achieve results that promote the development and creation of a knowledge-based society.

### 5.5 Short-run dynamics

The results of the cointegration tests are shown in Table 9. The absolute values of the calculated test statistics for all the residuals are less than its critical value at the 5% level, indicating that neither of the series are cointegrated. The variables in the model are cointegrated, indicating that the use of an error correction model mechanism representation is adequate to evaluate the short-run dynamics.

To determine the relationship in the short run, the estimated model results are reported in Tables 10 and 11. The Adj-R2 for the majority of the models is over 0.70, suggesting that such an error correction model fits the data reasonably well. More importantly, the error correction coefficient has a negative and highly significant sign. This result confirms the long-run relationship among the variables in this model.

These estimations indicate that variables such as scholarships, patents, trademarks and independence have long-run relationships, which is fundamental to defining adequate STI policies and determining their effectiveness in promoting knowledge generation and economic growth and development.

**Table 9** Cointegration tests for investments in science, technology and innovation activities (STIAs) and research development models

| Investments in science, technology and innovation activities (STIAs) model | Dickey-Fuller Test | Phillip-Perron Test | Investments in research and development (R&D) model | Dickey-Fuller Test | Phillip-Perron Test |
|---|---|---|---|---|---|
| Investments in STIAs—National PhD programmes | −2.837 | −2.813 | Investments in R&D—National master's programmes | −2.083 | −2.069 |
| Investments in STIAs—Total scholarships | −0.799 | −0.604 | Investments in R&D—National PhD programmes | −2.837 | −2.813 |
| Investments in STIAs—Number of research groups recognized by Colciencias | −0.992 | −0.955 | Investments in R&D—Total scholarships | −0.799 | −0.604 |
| Investments in STIAs—Scientific papers published | −1.904 | −1.914 | Investments in R&D—groups recognized by Colciencias | −0.992 | −0.955 |
| Investments in STIAs—Scopus citations | −1.944 | −1.964 | Investments in R&D—Scientific papers published | −1.904 | −1.914 |
| Investments in STIAs—Public expenditure on education as % of GDP | −2.746 | −2.753 | Investments in R&D—WoS SciELO citations | −2.663 | −2.652 |
| Investments in STIAs—Total national patents granted | −2.570 | −2.630 | Investments in R&D—Public expenditure on education as % of GDP | −2.746 | −2.753 |
| Investments in STIAs—Total international patents granted | −1.278 | −1.358 | Investments in R&D—Total national patents granted | −2.517 | −2.592 |
| Investments in STIAs—Trademarks | −1.288 | −1.388 | Investments in R&D—Total international patents granted | −1.278 | −1.358 |
| Investments in STIAs—Software registration | −3.438 | −3.447 | Investments in R&D—Trademarks | −1.541 | −1.333 |

**Table 10** Estimated regression model—estimates of the error correction representation, model 1: dependent variable investments in science, technology and innovation activities (STIAs)

| Parameter | Model [1] | Model [2] | Model [3] | Model [4] | Model [5] | Model [6] | Model [7] | Model [8] | Model [9] | Model [10] | Model [11] | Model [12] | Model [13] | Model [13] | Model [14] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Constant | 19.476** (9.127) | 8.850*** (2.978) | 3.322 (4.471) | 32.219*** (12.064) | 16.090*** (0.203) | 2.757 (4.083) | 14.850*** (3.548) | 4.608 (5.402) | 7.169*** (2.490) | 22.572*** (8.266) | 22.572*** (8.266) | 24.718 (90.463) | 164.84*** (61.55) | 15.599** (6.511) | − 15.643 (16.351) |
| National PhD pro-grammes | 0.002** (0.001) | | | | | | | | | | | | | | |
| Total schol-arships | | 0.000*** (0.000) | | | | | | | | | | | | | |
| Number of research groups recognized by Col-ciencias | | | 0.000 (0.000) | | | | | | | | | | | | |
| Scientific papers published | | | | 0.000*** (0.000) | | | | | | | | | | | |
| Scopus cita-tions | | | | | 0.294 (0.296) | | | | | | | | | | |
| Public expendi-ture on education as % of GDP | | | | | | 0.387 (0.309) | | | | | | | | | |
| Total national patents granted | | | | | | | 0.678*** (0.134) | | | | | | | | |

**Table 10** (continued)

| Parameter | Model [1] | Model [2] | Model [3] | Model [4] | Model [5] | Model [6] | Model [7] | Model [8] | Model [9] | Model [10] | Model [11] | Model [12] | Model [13] | Model [13] | Model [14] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total international patents granted | | | | | | | | 0.000* (0.000) | | | | | | | |
| Trademarks | | | | | | | | | 0.000*** (0.000) | | | | | | |
| Software registrations | | | | | | | | | | 0.000*** (0.000) | | | | | |
| Investment expenditures of Colciencias | | | | | | | | | | | 0.000*** (0.000) | | | | |
| Independence policy indicator for entity without reform | | | | | | | | | | | | −10.493 (29.714) | | | |
| Independence policy indicator for entity with reform | | | | | | | | | | | | | 163.11*** (61.24) | | |

**Table 10** (continued)

| Parameter | Model [1] | Model [2] | Model [3] | Model [4] | Model [5] | Model [6] | Model [7] | Model [8] | Model [9] | Model [10] | Model [11] | Model [12] | Model [13] | Model [13] | Model [14] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transparency indicator for entity without reform | | | | | | | | | | | | | | −12.511** (5.221) | |
| Transparency indicator for entity with reform | | | | | | | | | | | | | | | 21.596 (21.370) |
| Residual (−1) | −0.350 (0.634) | −0.390* (0.205) | −0,760** (0.321) | −1.280 (0.854) | −24.21*** (8.558) | −0.706** (0.322) | −0.223 (0.278) | −0.646* (0.376) | −0.440** (0.183) | −0.596 (0.585) | −0.596 (0.585) | −0.101 (0.485) | −0.575*** (0.193) | −0.332 (0.292) | −0.728** (0.352) |
| Adj-R-squared | 0.79 | 0.83 | 0.73 | 0.75 | 0.73 | 0.52 | 0.84 | 0.42 | 0.79 | 0.80 | 0.80 | 0.16 | 0.75 | 0.75 | 0.51 |
| F-value | 33.32 | 43.90 | 24.59 | 27.61 | 24.22 | 8.44 | 46.87 | 7.37 | 32.99 | 36.37 | 36.37 | 1.49 | 26.68 | 26.86 | 7.83 |

Notes: Figures in parentheses are the standard errors

*** Significant at the 1 percent level, ** Significant at the 5 percent level and * Significant at the 10 percent level

**Table 11** Estimated regression model—estimates of the error correction representation, Model 2, dependent variable investments in research and development (R&D)

| Parameter | Model [1] | Model [2] | Model [3] | Model [4] | Model [5] | Model [6] | Model [7] | Model [8] | Model [9] | Model [10] | Model [11] | Model [12] | Model [13] | Model [14] | Model [15] | Model [16] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Constant | 20.086*** (2.475) | 13.284*** (2.087) | 15.742*** (0.643) | 16.816*** (1.253) | 9.584*** (3.041) | 0.070 (0.107) | −0.360 (0.476) | − 15. 277 (33.392) | −0.190 (0.268) | −10.639*** (2.409) | −7.874*** (2.026) | −0.444 (0.2563) | −4.234 (9.745) | −5.025** (1.921) | −8.337*** (2.578) | 0.549 (0.787) |
| National master's programmes | 0.000 (0.000) | | | | | | | | | | | | | | | |
| National PhD programmes | | 0.002** (0.001) | | | | | | | | | | | | | | |
| Total scholarships | | | 0.000*** (0.000) | | | | | | | | | | | | | |
| Number of research groups recognized by Colciencias | | | | 0.000 (0.000) | | | | | | | | | | | | |
| Scientific papers published | | | | | 0.000*** (0.000) | | | | | | | | | | | |
| WoS SciELO citations | | | | | | 0.028 (0.042) | | | | | | | | | | |
| Public expenditure on education as % of GDP | | | | | | | 0.062 (0.074) | | | | | | | | | |

**Table 11** (continued)

| Parameter | Model [1] | Model [2] | Model [3] | Model [4] | Model [5] | Model [6] | Model [7] | Model [8] | Model [9] | Model [10] | Model [11] | Model [12] | Model [13] | Model [14] | Model [15] | Model [16] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total national patents granted | | | | | | | | 0.000** (0.000) | | | | | | | | |
| Total international patents granted | | | | | | | | | 0.000 (0.000) | | | | | | | |
| Trademarks | | | | | | | | | | 0.452*** (0.218) | | | | | | |
| Software registration | | | | | | | | | | | 0.752*** (0.191) | | | | | |
| Investment expenditures of Colciencias | | | | | | | | | | | | 0.037 (0.167) | | | | |
| Independence policy indicator for entity without reform | | | | | | | | | | | | | − 6.559 (14.207) | | | |

**Table 11** (continued)

| Parameter | Model [1] | Model [2] | Model [3] | Model [4] | Model [5] | Model [6] | Model [7] | Model [8] | Model [9] | Model [10] | Model [11] | Model [12] | Model [13] | Model [14] | Model [15] | Model [16] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Independence policy indicator for entity with reform | | | | | | | | | | | | | | 174.05*** (33.60) | | |
| Transparency indicator for entity without reform | | | | | | | | | | | | | | | −4.802*** (0.659) | |
| Transparency indicator for entity with reform | | | | | | | | | | | | | | | | 8.843 (11.974) |
| Residual (−1) | −2.810** (1.222) | −0.586 (1.056) | −0.641* (0.336) | −1.300** (0.550) | −2.129 (1.420) | −0.543 (2.404) | −0.079 (0.121) | −9.291 (20.445) | −0.112 (0.144) | −0.328* (0.168) | −0.406 (0374) | −0.995*** (0.330) | −0.618 (4.302) | −1.008 (1.064) | −1.768 (1.473) | −0.837** (0.372) |
| Adj-R-squared | 0.81 | 0.79 | 0.83 | 0.75 | 0.75 | 0.52 | 0.53 | 0.29 | 0.78 | 0.82 | 0.84 | 0.74 | 0.41 | 0.61 | 0.76 | 0.43 |
| F-value | 38.30 | 33.32 | 43.90 | 27.61 | 27.61 | 10.01 | 10.08 | 3.15 | 31.47 | 41.89 | 47.91 | 25.33 | 13.00 | 13.61 | 26.93 | 7.56 |

Notes: Figures in parentheses are the standard errors

*** Significant at the 1 percent level, ** Significant at the 5 percent level and * Significant at the 10 percent level

## 6 Conclusions

In this study, we analysed the new Colombian institution represented by the MSTI through different correlation exercises built with quantitative and empirical methods. We determined the importance of the transparency and independence of the new institution in Colombia to its mission to achieve new knowledge, technologies and innovation to promote growth and sustainable development.

The two models indicate the importance of adequate policies and the new MSTI for achieving better results in the generation of knowledge and the promotion of innovation and new technologies in the productive sector. Higher investments in STIAs could be generated through the higher transparency and independence associated with the new institution, and the variables related to human resources indicate a positive and significant effect on the numbers of national master's and PhD programmes, total scholarships, research groups recognized by Colciencias, public expenditure in education as percentage of GDP and investment expenditures of Colciencias.

The MSTI must operate with a significant degree of autonomy, and its mandate should be to encourage everything related to STIAs in coordination with general economic policy. The MSTI must have the essential characteristic of formulating policies with a long-term perspective independent of the political cycle.

This study establishes different policy implications, especially for new institutions and the new MSTI, based on the different possibilities identified in the analysis. The results can help with the following areas: increasing funds and determining effective allocation based on new government projects and STI requirements; identifying the main barriers experienced by STIAs and R&D investment with the aim of addressing new policy instruments to encourage these investments to achieve the expected results; determining priorities and selectivity for STIAs and R&D investments to direct them towards areas, activities, processes or projects with the greatest potential for internationalization and the highest value; and aligning STI policy with other policies related to human capital, productive development, foreign direct investment and competitiveness, among others. These issues are important for positioning STI and knowledge generation as drivers of productivity and competitiveness in Colombia to transform commodities into high-tech products and services with greater possibilities for commercialization and to sell knowledge and technology.

Future research should analyse the possibilities and priorities in STI investments to guarantee an effective transformation from knowledge to technology and innovation products; analyse and evaluate the efficient allocation of STI investments, taking into account financial sources and types; suggest new STI policies; determine the effects of STI investments and policies on strengthening value chains, competitiveness and knowledge spillover; and establish and allocate the necessary resources to guarantee effective knowledge results and promote development based on STI.

The findings of this study are important for establishing adequate governance for STI in Colombia and other emerging economies that seek to promote knowledge-based development and growth, support the application of technology and innovation, improve the productive sector and enhance the welfare of the population.

## References


Aboal, D., Tacsir, E.: Innovation and Productivity in Services and Manufacturing: The Role of ICT Investment (No. 012). United Nations University-Maastricht Economic and Social Research Institute on Innovation and Technology (MERIT) (2015)

Acemoglu, D.: Introduction to Modern Economic Growth. Princeton University Press, New Jersey (2009)

Aghion, P., David, P., Foraye, D.: Science, technology and innovation for economic growth: linking policy research and practice in 'STIG systems'. Res. Policy **38**, 681–693 (2009)

Álvarez, R.: The impact of R&D and ICT investment on innovation and productivity in chilean firms. Technical note no. IDB-TN-1056 (2016)

Barney, J.B., Hesterly, W.S.: Strategic Management and Competitive Advantage. Pearson/Prentice Hall, Upper Saddle River (2006)

Benavente, J.M.: The role of research and innovation in promoting productivity in Chile. Econ. Innov. New. Technol. **15**(4–5), 301–315 (2006)

Bernanke, B.: Promoting research and development: the government's role, in issues in science and technology 27, No. 4 (2011)

Bilbao-Osorio, B., Rodriguez-Pose, A.: From R&D to innovation and economic growth in the EU. Growth Change **35**(4), 434–455 (2004)

Caballero, R.J., Hammour, M.L.: Creative destruction and development: institutions, crises, and restructuring. NBER Working Paper No. 7849 (2000)

Cavalcanti, M.: Gestão de empresas na sociedade do conhecimento. Campus, Rio de Janeiro (2001)

Commander, S., Harrison, R., Menezes-Filho, N.: ICT and productivity in developing countries: new firm-level evidence from Brazil and India. Rev. Econ. Stat. **93**(2), 528–541 (2011)

Cotte, A.: Scientific policy, social equality and agency theory. Revista CIFE: Lecturas de Economía Social **20**(32), 13–16 (2018)

Cotte, A., Andrade, J.: Expenditure in science, technology and innovation activities. In: Pardo, C., Cotte, A. (eds.) Science and Technology Indicators, pp. 23–54. Bogotá (2018)

Cotte, A., Andrade, J.: Expenditure in science, technology and innovation activities. In: Pardo, C., Cotte, A. (eds.) Science and Technology Indicators, pp. 39–66. Bogotá (2019)

Cotte, A., Andrade, J., Pardo, M.: Applying a new methodology to measure investment in R&D and science and technology activities: The case of Colombia. In: Pardo, C., Cotte, A., Fletscher, S. (eds.) Analysis of science, technology, and innovation in emerging economies, pp. 21–35. Palgrave Macmillan, Cham (2019)

Crespi, G., Tacsir, E., Vargas, F.: Innovation and productivity in services: empirical evidence from Latin America. IDB Technical Note No. IDB-TN-690. Inter-American Development Bank, Washington (2014)

Crosby, M.: Patents, innovation and growth. Econ. Rec. **76**(234), 255–262 (2000)

Datta, A., Reed, R., Jessup, L.: Commercialization of Innovations: An Overarching Framework and Research Agenda. Cleveland State University, Business Faculty Publications, Cleveland (2013)

ECLAC: Science, technology and innovation in the digital economy. The state of the art in Latin America and the Caribbean. https://repositorio.cepal.org/bitstream/handle/11362/40840/1/S1600832en.pdf (2016)

Enders, W.: Applied Econometric Time Series. Wiley, Hoboken (2014)

EPRS: A governance framework for algorithmic accountability and transparency. https://www.europarl.europa.eu/RegData/etudes/STUD/2019/624262/EPRSSTU(2019)624262EN.pdf (2019)

European Commission: The role of science, technology and innovation policies to foster the implementation of the sustainable development goals (SDGs). https://ec.europa.eu/knowledge4policy/publication/role-science-technology-innovation-policies-foster-implementation-sustainableen (2015)

Freeman, C.: Technology and Economic Performance: Lessons from Japan. Pinter, London (1987)

G7 Academies: New economic growth: the role of science, technology, innovation and infrastructure. https://royalsociety.org/~/media/about-us/international/g-science-statements/2017-may-3-new-economic-growth.pdf?la=en-GB (2017)

Griffith, R., Redding, S., Reenen, J.V.: Mapping the two faces of R&D: productivity growth in a panel of OECD industries. Rev. Econ. Stat. **86**(4), 883–895 (2004)

Grossman, G.M., Helpman, E.: Innovation and Growth in the Global Economy. The MIT Press, London (1991)

Hall, B.H., Lotti, F., Mairesse, J.: Evidence on the impact of R&D and ICT investments on innovation and productivity in Italian firms. Econ. Innov. New. Technol. **22**(3), 300–328 (2013)

Haragadon, A.: The business of innovating: bringing low-carbon solutions to market, center for climate and energy solutions (2011)
Hulten, C., Isaksson, A.: Why development levels differ: the sources of differential economic growth in a panel of high and low income countries. NBER working paper No. w13469 (2007)
IDB: Science, technology, and innovation in Latin America and the Caribbean. a statistical compendium of indicators. publication code: IDB-MG-101 (2010)
Kim, H., Shin, J., Lee, S.: A new approach to efficient ratio: A case of South Korea's research and development investment. J. Eng. Technol. Manag. **51**, 1–9 (2019)
Křistkova, Z.: Impact of R&D investment on economic growth of the Czech Republic: a recursively dynamic CGE approach. Prague Econ. Pap. **4**, 412–433 (2012)
Liik, M., Masso, J., Ukrainski, K.: The contribution of R&D to production efficiency in OECD countries: econometric analysis of industry-level panel data. Baltic J. Econ. **14**(78–100), 1 (2014)
MacQueen, J.: Some methods for classification and analysis of multivariate observations. In: Proceedings of 5th Berkeley Symposium on Mathematical Statistics and Probability. University of California Press, Berkeley, vol. 1, pp. 281–297 (1967)
Metcalfe, J.S.: The economic foundations of technology policy: equilibrium and evolutionary perspectives. In: Stoneman, P. (ed.) Handbook of Economics of Innovation and Technology Change. Blackwell, Oxford (1995)
Mukhopadhyay, D.: Post-independence science policy and science funding in India. Curr. Sci. **107**, 1983–1987 (2014)
OCyT, National University of Colombia, Rosario University: Colciencias forty years. Between legitimacy, regulations and practice. https://www.ocyt.org.co/proyectos-y-productos/colciencias-cuarenta-anos-entre-la-legitimidad-la-normatividad-y-la-practica/ (2013)
OECD: OECD Best practices for budget transparency. https://www.oecd.org/gov/budgeting/best-practices-budget-transparency.htm (2002)
OECD: OECD science, technology and innovation outlook 2018. Adapting to technological and societal disruption. https://www.oecd.org/sti/oecd-science-technology-and-innovation-outlook-25186167.htm (2017a)
OECD: OECD budget transparency toolkit. practical steps for supporting openness, integrity and accountability in public financial management. https://www.oecd.org/gov/oecd-budget-transparency-toolkit-9789264282070-en.htm (2017b)
Pardo Martínez, C.I., Cotte Poveda, A., Ronderos, R.: An analysis for new institutionality in science, technology and innovation in Colombia using a structural vector autoregression model. Eur. Res. Stud. J. **XXII**(2), 218–228 (2019). https://doi.org/10.35808/ersj/1434
Pindick, R., Rubinfeld, R.: Econometric Models and Economic Forecasting. McGraw-Hill/Irwin, New York (1997)
Rebelo, S.: Long run policy analysis and long run growth. J. Polit. Econ. **99**(3), 500–521 (1991)
Rezende, J., Correia, A., Gomes, B.: The intellectual capital and the creation of value in research units linked to the Brazilian ministry of science technology and innovation. RAI Revista de Administração e Inovação **14**, 199–215 (2017)
Romer, P.M.: Increasing returns and long-run growth. J. Polit. Econ. **94**(5), 1002–1037 (1986)
Romer, P.M.: Endogenous technological change. J. Polit. Econ. **98**(5), 71–101 (1990)
Schumpeter, J.A.: Business cycles: a theoretical, historical, and statistical analysis of the capitalist process (1939)
Todaro, M.P.: Economic Development, 6th edn. Longman, New York (1997). **(Chapter 4)**
Trott, P.: Innovation Management and New Product Development, 5th edn. Financial Times Press, Upper Saddle River (2011)
UNCTAD: A Framework for Science, Technology and Innovation Policy Reviews. Harnessing innovation for sustainable development. https://unctad.org/en/PublicationsLibrary/dtlstict2019d4en.pdf (2019)
UNESCO: Science, technology and innovation systems and governance. https://en.unesco.org/science-policy/stigovernance#sti-development (2017)
United Nations: Commission on science and technology for development. Report on the nineteenth session. https://unctad.org/meetings/en/SessionalDocuments/ecn162016d4en.pdf (2016)
UNCTAD: The UNCTAD STI capacity development course. https://unctad.org/en/PublicationsLibrary/dtlstictinf2019d1en.pdf (2019)
USAID: The role of science, technology, innovation, and partnerships in the future of USAID. https://www.nap.edu/catalog/24617/the-role-of-science-technology-innovation-and-partnerships-in-the-future-of-usaid (2017)

Woolthuis, R.K., Lankhuizen, M., Gilsing, M.: A system failure framework for innovation policy design. Technovation **25**(2005), 609–619 (2005)
Zalewski, R.I., Skawinska, E.: Impact of technological innovations on economic growth of nations. Syst. Cybern. Inform. **7**(6), 35–40 (2009)