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RESEARCH ARTICLE

The Current Agricultural Technology Transfer Policy in Colombia Modeled through Dynamic Performance Governance

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ABSTRACT

This paper accounts for public policies on agricultural technology transfer policy in Colombia and is modeled on the actual policy, illustrating how the "Dynamic Performance Governance" framework can solve some problems that have occurred and currently arise, and could affect the long-term objectives of the National Agricultural Innovation System. Our results reveal a virtuous circle (positive loop) potentiating the country's growth and development, based on government investments in science and technology to increase productivity in the Colombian countryside, thus increasing both sustainability and gross agricultural domestic product. However, this has not been achieved due to two types of technology transfer delays for rural producers. The first one is generated by the definition of the technological territorial demands followed by decision-makers when prioritizing interventions. The second one relates to the lack of agricultural extension and technical assistance services that restrict the results generated by agricultural research from being transferred and their subsequent adoption by end-users.

Keywords: National Agricultural Innovation System; Productivity; Science & technology; Transfer Delays

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1. Introduction

Acemoglu and Robinson [1] proposed that inclusive institutions favor the distribution of power in society, constrain its arbitrary exercise, enforce property rights, ensure equitable distribution of resources, and encourage investment in skills and new technologies. Actually, through the sale or lease of part or all of the property rights owners hold, they could capture the benefits produced by long-term investments, and at the same time produce new technologies [2, 3]. Technological change is considered an element that explains the development of a country, so technological modernization increases productivity [4].

Productivity overlaps the spectrum of development and economic growth. The reduction of poverty depends on education and its reflection on research and technological developments, which, in turn, increases economic productivity, resulting in sustained acceleration of growth and poverty reduction [5]. Both academics and policymakers in Colombia nowadays agree that knowledge contributes to economic growth, and technological progress is recognized as a factor in differences in productivity and welfare [6].

Romer [7] stated that investment involves not only increases in capital stock but also in the technology as output in research; a permanent increase in the total stock of human capital in the population leads to an increase in the proportion of human capital as the stock of knowledge and a more than proportional increase in the amount of human capital that is dedicated to the research sector.

In the early years of the Green Revolution, technology adoption in rice and wheat was rapidly adopted, causing increased productivity in agriculture, but this increased food production has contributed to lower food prices globally [8]. The COVID-19 pandemic shows us that there is a global food shortage, as well as widespread poverty, increasing food insecurity, and a critical weakness in the food supply system [9, 10].

The United Nations Sustainable Development Goals (SDGs) point to a better and more sustainable future for mankind, especially the goals of no poverty (SDG1), zero hunger (SDG2), industry, innovation and infrastructure (SDG9), and achieving sustainable life on land (SDG15), productivity returns, not as the only solution, to provide answers and achieve the SDGs; therefore, technology generation and transfer become paramount. Expanding productivity capacity becomes an element key to achieving development progress [11].

To ensure the population's food security in 2030 and beyond, new and existing applications of science, technology, and innovation (STI) are required across food systems. This is critical, not only to ensure a nutritious food supply but also for harnessing agriculture and the broader food system as a driver of economic and sustainable development [11].

In the same way, the pandemic caused by SARS-CoV-2 in 2020 shows us the importance of the food production system by allowing the supply of the local, regional, and global markets. Technology, especially biotechnology, could be a tool in the fight against hunger and poverty. Biotechnology can contribute to increased productivity in two ways: the first is by reducing losses to pests and pathogens, and the second is by increasing photosynthetic efficiency [12].

The urban and landless vulnerable communities in developing countries need cheaper food. Biotechnology has the potential to contribute to improved yields, reduced risks, reduced poverty and food security for farmers, and plentiful nutritious and affordable food for consumers [13].

Both private and public investments are important to promote technology adoption, stimulate complementary on-farm investment and input use, and are needed for marketing the agricultural goods produced [14–16].

In Colombia, technological change is considered a driver of the country's development, so technological modernization increases productivity [4]. Also, STI has been identified as a source of development and economic growth, thus requiring state policies and strategies that increase the country's capacity to generate and use scientific and technological knowledge [17].

To achieve increases in productivity and farmer welfare, technological progress and the transfer of technology have been major contributors [18, 19]. In the agricultural sector, efforts to improve processes, plant varieties, or tools alone are insufficient if the technology is not effectively transferred and adopted by agricultural producers. For instance, the percentage of land cultivated with improved maize varieties in sub-Saharan Africa around 2010–2012 varied significantly by country: 54% in Uganda, 35% in Tanzania, 95% in Nigeria, 43% in Malawi, and 28% in Ethiopia [20, 21].

In the past, the focus of agricultural research was to increase production, productivity, and profits; however today, farmers and policymakers are faced with complex choices, because they have a lot of technologies that are available with the aim of being a sustainable way, which often implies changing farm practices and using different technologies [22].

In some countries, technology transfer has been accompanied by policies over the years. For instance, in Colombia, the transfer of technology from the R&D entities is not a new phenomenon [23].

Colombia lagged behind the USA in supporting agriculture through government entities and initiatives. While in the USA, the Agricultural Extension Service was established in 1914 to promote agriculture as a federal technology-transfer policy, in Colombia the initiative came from a private entity with governmental support, the National Federation of Coffee Growers, which created the Coffee Research Center (Cenicafé) in 1938, but it was only until 1962, when the Colombian Agricultural Institute (ICA) was created, among many other responsibilities, to coordinate and intensify the extension of agricultural sciences.

This paper examines the Dynamic Performance Governance (DPG) framework and the dynamic hypothesis that we call the virtuous circle of transference of technology, in which investment in Agricultural Science, Technology, and Innovation (ASTI), and education will lead to a stock of knowledge and technologies that, when transferred and adopted by the agricultural producer, will increase productivity and through this, there will be growth and development.

We carried out an approach that addressed a logical understanding of the behavior of the technological transfer policy over the years, encompassed the following steps: (1) identifying important stylized facts that support the proposed hypothesis; (2) analyzing STI policies and strategies for the agricultural sector in Colombia; (3) mapping the stakeholders and their roles plus identifying the constraints; and (4) performing an analysis of the Law 1876/ 2017, through the DPG framework, leading to the conclusions and final recommendations of this work.

2. Materials and Methods

2.1. Stylized Facts

The literature explains how product knowledge is the most powerful source of wealth generation in any society, that infrastructure is necessary but can only work properly when it is available, and workers have adequate product knowledge. The same occurs with technology, although it is available, which does not necessarily mean it works efficiently for growth and development generation.

Meanwhile, government investments in education, research, both basic and applied, innovation, and the transfer of knowledge, machinery, and products, lay the basis for growth and development that will provide greater well-being to its citizens [24]. However, if these investments in education and research are due to a State Program, and not a government program, the scope, vision, and objectives will be long-term, regardless of the agreements of the government in office.

Expenditures on scientific activities and research and development could be a proxy for technological change and a country's innovative indicator [25]. Also, R&D intensity is one of several indicators used to measure progress toward achieving SDG9 on innovation [26]. However, Zepeda [27] considers that the development of technology does not always result in its adoption because, in some cases, the technology being developed is not appropriate. Another review of the case studies on technology adoption provides support for the hypothesis that there are profitable technologies that are not diffused widely because of a weak extension system [21]. Ren [28] argues that the new technology usually conflicts with the existing formal structures, managerial or technical of the possible adopters.

During 2021, the countries of the Organization for Economic Cooperation and Development (OECD) reported an average expenditure on research and development activities of 2.7% of their Gross Domestic Product

(GDP), while for Colombia the indicator is a pitiful 0.2% of the GDP in 2020 [29, 30]. This overwhelming difference is even more noticeable if the data is compared to current values and not as a percentage of GDP.

However, during the period 1990–2018, public investment in Science, Technology, and Innovation Activities (ACTI) and training in the agricultural sector was on average 0.06% of the Colombian GDP. In absolute terms, ACTI in 2021 was COP 544,393.67 million at constant levels of 2015, a value that decreased by 12.54% compared to 2020; while GDP and GDPA grew by more than 10%. In 2021, the investments in agricultural ACTI are the third lowest in the last decade, exceeding those reported in 2017 and 2018.

Between 2012 and 2021, the investment came from the General System of Royalties (SGR). Between 2016 and 2018, there was a drop in said investment given the transition of the STI policy of the sector around the creation of new entities and the enactment of Law 1876 of 2017. During this transition process expenditures decreased, such as those for technical assistance, among others, returning to the 2007 figures.

In the meantime, public investment in ACTI and training of the sector concerning agricultural GDP represented approximately 0.06% as a proportion of GDP and 0.81% as a proportion of GDPA [31]. Between 2020–2021, 4,893 projects were approved and implemented by 82 entities [31].

As regards education in Colombia, the National Information System for Higher Education (SNIES) reported an improvement in 2021, with 2,576 Full-Time Equivalent (FTE) positions of researchers who carryout science, technology and innovation activities for the agricultural sector. Regarding graduates of master's and doctoral programs related to the sector, the country had a total of 690 graduates in 2021, representing a total of 10.27% of master's degrees and 2.03% of Ph.D.

However, for September 2019, the SNIES reported a total of 24,747 academic programs distributed across seven levels of education, of which 52% were active. Regarding the agricultural sector, a total of 970 programs were identified, representing 7.6% of the active education programs. 50% of the programs offered in the agricultural sector corresponded to technical, technological, and professional levels, with the technological level having the highest share of 24%.

Master and doctoral programs represented 27% of the offer, with the doctoral level showing the lowest offer with only 4.6%. Agricultural and forestry sciences registered only one program offered, while biology, microbiology, and related programs registered 13 programs.

At the same time, the personnel dedicated to R&D in the agricultural sector in 2018 amounted to a total of 2,244 researchers working full-time for the sector, revealing an average annual growth rate of 5.6% since 2001. This figure is the result of the 48.2% increase that occurred between 2017 and 2018 due to the inclusion of unreported data from 30 institutions. However, between 2001 and 2009, growth was mainly marked by policies and incentives such as the Transition Program for Agriculture and the Rural Mean [32].

On the other hand, during 2010 and 2011, there was a drop in the number of researchers, a fact that was aligned with the 40% investment reduction in the ACTI of the sector, which began in 2006. However, since 2012, there has been a revival of investment in ACTI in the sector, showing a boom in 2015 and then decreasing again.

This analysis of education and spending on STI shows a disappointing picture, further exacerbated by data generated by the World Intellectual Property Organization (WIPO). While the world generated 3,326,300 patents, 2,145,960 utility models, 14,321,800 brands; 1,312,600 industrial designs, and 20,210 plant varieties, Colombia only participated with 2,223 patents, 188 utility models, 45,656 brands, 638 industrial designs, and 168 vegetable varieties. Indeed, Colombia contributed between 0.01% and 0.83% to the world stock of STI in 2018. However, since 2018, the offices of China, Colombia, the European Union, Spain, Ukraine, and the United Kingdom has accounted for most of the growth of plant varieties [33].

The production of knowledge and technology is not only given in terms of patents, but also by the accumulation of documents published in indexed journals. Faced with this, Scopus shows that 3,198,687 documents were published during 2018, of which 799,612 were from areas related to the agricultural sector. On the same date, Colombia published 13,300 documents, of which 3,281 were related to the agricultural sector.

On the other hand, to measure the efficiency of agricultural systems, organizations such as the Food and Agriculture Organization of the United Nations (FAO), the International Food Policy Research Institute (IFPRI), and the United States Department of Agriculture apply the so-called Total Factor Productivity (TFP).

Fuglie [34] defined TFP as the actual output produced by a company or industry over a period divided by the actual input used by that company or industry during the same time.

The actual input refers to the combined use of land, labor, capital, and material resources used in production. The TFP is calculated as the ratio of total agricultural production to total production inputs. The latest data shows that the world TFP index (the baseline year 2005 = 100) was 121, whereas the TFP for Colombia was 106. The results showed a world agricultural productivity growth of 0.0059 but a decrease in the TFP for Colombia of 0.031 [35].

Finally, it is important to highlight that the 2014 National Agricultural Census showed that of the 2.5 million agricultural producers, only 16% received technical assistance. Therefore, the Rural Development Agency (ADR) generated an action plan that managed to train 64 entities providing agricultural extension services (Epsea), 20,000 users were served with extension services; and 36 Epsea were authorized to provide the service in 2019 [36].

2.2. Science, Technology and Innovation (STI) Policies, Strategies, and Stakeholders in the Colombian Agricultural Sector

Moncayo [37], pointed out that the first manifestations of STI policies occurred in the 1960s; before this date, government measures on the subject were limited to specific scientific research programs and projects in the fields of agriculture and health.

Other researchers consider that the Science and technology policy was explicitly included a few years later, in the 1979–1982 National Integration Plan, which was developed by former Colombian President Julio César Turbay Ayala. The modernization of the State in the 1960s led to the creation of a variety of entities such as the Administrative Department of Science, Technology, and Innovation (Colciencias), ICA, the Colombian Veterinary Products Company (VECOL), and the National Institute of Marine Research (Invemar) [38].

Even though the Research Centers ("Ceni´s") were not part of the STI policy, they were not excluded, and, by 1938, the National Federation of Coffee Growers created the Coffee Research Center (Cenicafé), and the sugar mills and sugarcane growers created the Colombian Sugarcane Research Center (Cenicaña) in September 1977. The Association of Banana Merchants and Growers of Colombia (AUGURA) created Cenibabano in 1985; palm growers created the Oil Palm Research Center (Cenipalma) in 1991; and the Cereal and Legumes Research Center (Cenicel) was created in 2012.

Until 1987, the ICA and the Colombian Institute for Agrarian Reform (Incora) had overseen agricultural assistance, a situation that changed with Decree 77 of 1987 [39], leaving the municipalities with the responsibility to carry out their functions.

In 1989, Decree 501 [40] modified the structure of the Ministry of Agriculture and created a sub-direction for technology transfer in charge of imparting technical instructions aimed at achieving the coordination and operation of the National System for the Transfer of Agricultural Technology (Sintap). Sintap was created under Decree 1946 of 1989 [41] to provide the guiding principles, the structure, and functions of the system and specifications of the technical assistance so that its operation would be aligned with the government's needs. For Perry [42], Sintap should promote national production to achieve self-sufficiency and the improvement of social and economic performance by modernizing technology in agriculture, livestock, forestry, and fish farming.

Law 29 of 1990 [43] issued provisions for the promotion of scientific and technological research. This law highlighted the State's obligation to incorporate science and technology into the country's economic and social development programs and to formulate science and technology plans for both the medium and long term. To comply with all the above, the government dictated Decree 585 of 1991 [44], to create the National Council for Science and Technology while Colciencias was reorganized.

This modernization of the Colombian State, under the legal framework of science and technology, along with Decree 393 of 1991 [45] and Decree 2141 of 1992 [46], allowed the separation of functions of ICA in 1994. This Institute oversaw the health, prevention, control, and supervision of agricultural supplies, as well as the registration of new products. A new institution, the Colombian Corporation for Agricultural Research (Corpoica), was created, which in 2018 changed its acronym and became Agrosavia whose purpose is the generation of scientific knowledge and agricultural technological development.

In July 1995, the Colombian government obtained external financing to create the National Program for Agricultural Technology Transfer (Pronatta) to boost the productive capacity of the lowest income agricultural sector and consolidate the Sintap [47].

Pronatta contributed to the technology transfer component of projects by entities such as the Integrated Rural Development Fund (DRI), the National Rehabilitation Plan (PNR), Incora, the Colombian Institute of Hydrology, Meteorology and Land Adaptation (Himat), and the National Institute of Renewable Natural Resources and Environment (Inderena).

Six years after Corpoica was created, Law 607 of 2000 [48] created the National System for Agricultural Science and Technology (SNCTA) and the Rural Direct Technical Assistance Subsystem (SATDR), which were intended to guarantee agricultural assistance, linked to the municipal entities.

In 2004, to support the optimization of resource investment in knowledge and technological innovation for agricultural and agribusiness production, to reduce poverty in rural areas, and to mitigate the effects of the economic opening, the government created a Transition Strategy for Agriculture and Rural Environment (PTA). Its purpose was to strengthen scientific, technological, and innovation capacities, as well as technology transfer and service capacities, to increase the productivity and competitiveness of national agricultural production and overcome rural poverty and the great social inequalities that prevail in Colombian agriculture [32, 49].

Four years after the Vision Colombia: II Centenary document, under Law 1286 of 2009 [50], the National System of Science, Technology, and Innovation (SNCTI) was created, as well as the Advisory and Departmental Councils. Additionally, this law regulated the operation of the Municipal Units for Agricultural Technical Assistance (Umata) and defined the rural technical assistance service as a public and mandatory service, in charge of the municipalities.

In September 2016, the Strategic Plan for Science, Technology, and Innovation of the Colombian Agricultural Sector 2017–2027 (PECTIA, from its Spanish acronym) was created as a guiding framework for the STI policy in the agricultural sector. Its resources were allocated to promote technical change, the generation of value, and the periodic evaluation of its results regarding sustainability, productivity, and competitiveness. This document states that the transfer of technology is essential for linking and effective adopting of the offers originated in productive chains. It also states that technical assistance is the mechanism that integrates research, technology transfer, and adoption by producers [51].

After a long peace process, in April 2017, a document called "Final agreement for the termination of the conflict and the construction of a stable and lasting peace" was signed, and 14 principles were included in the so-called chapter "Towards a New Colombian Field: Integral Rural Reform". The rector principle of this chapter was to ensure productivity through programs that consider innovation, science and technology, technical assistance, and other connotations that guarantee a healthy, adequate, and sustainable diet for the population [52].

By the end of 2017, Law 1876 [53] was drafted and governed, creating the National Agricultural Innovation System (SNIA) repealing all contrary provisions, particularly Law 607 of 2000 [48]. The SNIA was created and integrated by three subsystems: The National Subsystem for Agricultural Research and Technological Development (SNIDTA), the National Subsystem for Agricultural Extension (SNEA), and the National Subsystem for Training and Training for Agricultural Innovation (SNFCIA).

To expand the scope of agricultural and rural extension, Resolution 464 of 2017 [54] defined the strategic guidelines of public policy for Farming, Family, and Community Agriculture (ACFC for its Spanish acronym). Rural extension capacity building for this type of producer is one of the structuring axes and makes clear the actors involved in this process.

Subsequently, to support the governance of the SNIA, two resolutions were created, the Resolution 407 of 2018 [55] and Resolution 422 of 2019 [56]. The first one regulated the technical matters of the SNIA, establishing, among others, the processes for updating PECTIA and the roles they fulfill, as well as the instances of the regional and national orders that participate. The second one regulated the authorization of the entities providing agricultural extension services (EPSEA, from its Spanish acronym).

To consolidate the SNCTI, in 2019, the Ministry of Science, Technology, and Innovation (MinCiencias) was created through Law 1951 of 2019 [57] and Decree 226 of 2019 [58] as the "agency for the management of the public administration, rector of the sector and SNCTI, in charge of formulating, guiding, directing, coordinating, executing, implementing and controlling the State's policy in this matter, following development plans and programs" [58]. Nevertheless, Law 1951 of 2019 [57] was declared unenforceable with effects deferred to two legislatures by Sentence C-047 of 2021 [59] and repealed by Art. 22 of Law 2162 of 2021 [60], which in turn regulated the conditions of the Ministry of Science, Technology, and Innovation.

2.3. Stakeholders

Recognizing the past and present of technology transfer policies allows understanding of the STI dynamics in the agricultural sector. It is also necessary to define the stakeholders and their roles (**Table A1**), understand their relationships and possible failures in the mechanisms of transmission of knowledge and technology to Colombian producers.

Stakeholders can be divided into two big groups, those that are part of the agricultural sector and those that are part of the technology transfer policy. The first group is a set of entities that start from the bottom up, with agricultural producers and producer associations who demand sectoral goods or services up to regional and national policymakers and decision-makers. The second group is a subset of the first group, and it is stipulated in Law 1876 of 2017 [53].

Policymakers & decision-makers. This group is made up of national and regional government entities that directly or indirectly influence the agricultural sector. MADR and DNP are the two institutions that head the list of government organizations, since they derive policies directly attributable to the sector.

Advisory offices. In the advisory offices, we found entities at the international, national, and regional levels that serve as support to policymakers and decision-makers.

Funders. This group is made up of those that generate liquidity for the sector to develop the programs that are required and may also have an international, national, or regional origin.

Coordinators. This group oversees ordering the aspects that makeup the activities to ensure that the proposed objectives are achieved by the policies and programs.

Knowledge & data generators. Entities that produce, both, data and results that allow research and decision-making to be carried out for the sector.

Knowledge & results transferors. This group includes entities that carry out technology transfer, from knowledge to machinery and biotechnology.

Stakeholders can also be classified by the type of technology used:

Domestic users. The Colombian user groups for transferred technologies include small and medium agricultural producers and a few large producers because they have greater access to foreign technologies. Other domestic users are the State and local governments. They can use the technologies in two ways: first, they can be used directly to improve community services, and second, they can use spinoffs to indirectly channel them to local businesses and entrepreneurs like seed producers.

Scientific-community users. According to Rood [23], this group, in both the public and private sectors, is interested in advancing the state of the art or the level of knowledge in their fields, and in using research findings for educational purposes.

Overseas users. Some other-country users with climatic conditions similar to Colombia have targeted audiences, as well as countries with international treaties with Colombia.

2.4. Analysis of the Current Agricultural Technology Transfer Policy

As seen so far, there is no single document that accounts for the policy of technology transfer to the agricultural sector in Colombia. It is evident that Law 1876 [53], created the National System for Agricultural Innovation (SNIA) and through the Agricultural Extension Subsystem oversees the transfer of the technology generated from research and innovation by the different entities that deal with it.

However, Resolution 407 of 2018 [55], shows the national instances and the operation of the transmission of the demands of producers and production chains to the SNCTA. This scheme starts from the regional instances where the demands come from and go through the ASTI boards, and depending on the origin of the demand, it will go to the respective committee.

If the demand comes from the ACFC, it will go through the technical advisory subcommittee of the ACFC; otherwise, the process will affect the national organizations of the productive chains and the management of agricultural and forestry chains of the MADR. At this point, the demand will reach the Technical Secretariat of the SNIA Superior Council and will go through its technical committee where it is determined whether the need for the territory merits continuing to superior stays and giving it a solution.

Figure 1 shows how the stakeholders of SNIA are supported by three subsystems, each one supplied with policies, instruments, and actors to fulfill its purposes. The first is the National Subsystem for Agricultural Research and Technological Development (SNIDTA), which supervises research, technological development and innovation activities, and agricultural transfer. The SNIDTA is coordinated by MADR and the Ministry of Science.

The second is the National Training and Subsystem for Agricultural Innovation (SNFCIA), which oversees coordinating the training actions that impact the R&D&I processes of the agricultural sector and is coordinated by the MEN.

The third one, the National Agricultural Extension Subsystem (SNEA) will guide, plan, implement, monitor, and evaluate the provision of the agricultural extension services, under the coordination of the MADR with support from Agrosavia.

In terms of the agricultural extension service, this was conceived as a public good that includes comprehensive support actions to diagnose, recommend, update, train, transfer, assist, empower and generate competencies in agricultural producers. The goal is that growers incorporate the practices, technological products, technologies, knowledge, and behaviors to improve their competitiveness, sustainability, food security, and development as integral human beings.

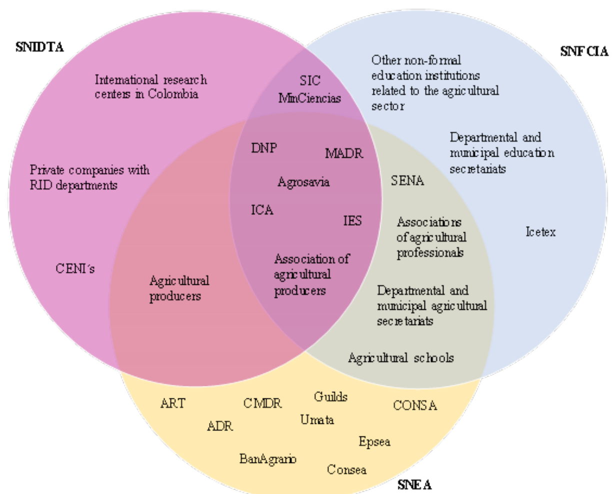

Figure 1. Venn diagram of stakeholders, by SNIA subsystem.

Note: The National Council of Secretaries of Agriculture (Consa), the Municipal Councils for Rural Development (CMDR), and the Sectional Councils for Agricultural, Fisheries, Forestry, Commercial, and Rural Development (CONSEA) are spaces for coordination and coordination composed of industry representatives.

Agricultural extension services play a crucial role in supporting producers by facilitating their connection to knowledge and technologies aimed at improving their quality of life. The vision of agricultural extension is comprehensive, focusing not only on promoting technical advancements within the production chain but also on advising and supporting producers. This holistic support is designed to provide growers with access to credit, property formalization, certifications in Good Agricultural Practices (GAP) and Good Handling Practices (GHP), and participation in other government programs developed for the Colombian agricultural sector.

However, for producers to receive the agricultural extension service, they must be registered in the user registry provided by MADR and pay a fee for the provision of the public service. This service will be subsidized according to the availability and concurrence of resources, and it will be collected by the municipalities. The fee will be borne by the local councils and will be established by ordinance, where the authority setting the fee must also be indicated.

Law 1876 of 2017 [53] established the National Fund for Agricultural Extension Services (FNEA), aimed at financing the provision of public agricultural extension services through the Departmental Plans for Agricultural Extension (PDEA). The resources allocated from the country's general budget to subsidize agricultural extension services are transferred to departments or municipalities to ensure the effective implementation of these services.

3. Results

A Theoretical Approach to the Technology Transfer Policy Model through DPM

Modeling through Dynamic Performance Governance (DPG) shares many traits with Dynamic Performance Management (DPM), but it is specifically tailored to governance. Both DPG and DPM are dynamic analysis frameworks that enable the identification of temporal and spatial offsets. This allows policymakers to distinguish delays that influence the effectiveness of policies and the achievement of their goals [61, 62].

DPM is a practice that supports a descriptive approach in policy analysis to illustrate and discuss the causes behind the investigated phenomena [61–67].

According to Bianchi et. al (2021) [68], DPM is a framework that fosters policy coordination and implementation, supporting the cascade process of delivering performance goals from the political level to the administrative units at the agency-level. The policy level looks at community outcomes [66]; while the agency level looks at five factors: organizational culture, human capital and capacity, agency support for the National Performance Review, leadership and oversight, and bureaucracy [69].

The starting point of the model for the transfer of agricultural technology in Colombia is given by the dynamic hypothesis obtained from the joint work of the SNIA subsystems. This hypothesis seeks to generate a virtuous circle between strengthening the capacities of human capital, through education and training, research and development of technology, and technology transfer through agricultural extension, not only to improve productivity and competitiveness but also to generate income and improve the quality of life of agricultural producers.

Figure 2 shows the virtuous circle of technology transfer in the agricultural sector, which begins with the investment made in STI, represented by government spending on second and third education levels (technicians, technologists, professionals, masters, and doctorates).

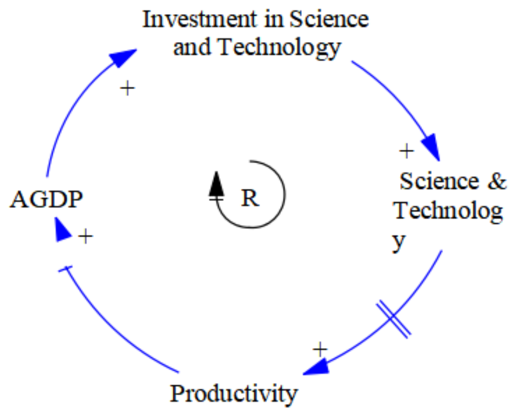

Figure 2. Initial dynamic hypothesis: the virtuous circle of agricultural technology transfer.

Public resources are also invested in agricultural research and development. The efforts of universities and research centers to contract social capital and develop new knowledge and technologies, as well as investments made by private companies that have Research, Development & Innovation (R&D&I) departments.

All the above generate a stock of technological knowledge, products, and services that will be transferred to agricultural producers. Once the transfer process takes place and technology is adopted by producers, they will increase their productivity, allowing them to obtain higher incomes and an improved quality of life as measured by Agricultural Gross Domestic Product (AGDP).

Finally, economic growth will translate into reinvestments in education, science, statistics, and technology, completing the virtuous cycle.

In **Figure 2**, it is also shown that within the positive loop, there is a delay between science and technology and productivity, which is generated by the transfer of technology in the Colombian agricultural sector in two ways.

The first delay is due to the transmission of knowledge needs and technology to the entities that will supply them, and the second one is caused by the transfer and adoption of technology among producers.

In the first case, the delay arises since the demands for technological knowledge, products, and services from the producers to those who supply them are not transmitted directly. The transmission of demands depends on the type of knowledge, technological product, or service that the agricultural producer requires, the urgency to satisfy the need for the country, the type of producer, and the provider of the technology.

For the second case, the delay is due to the transmission of technology by rural extension agents or technical assistants to producers and the delay in the adoption of technology by producers.

The analysis of the transmission behavior of technology in the agricultural sector reveals that delays depend on several factors. These include the management capacity of the organization addressing the need, its negotiation power relative to the government, the socioeconomic impact of the technology, and the urgency of the technological solution for the country.

Consequently, there is no specific time for a technical or technological demand to reach its solution, it depends on how long it takes to reach the Technical Committees of the SNIA Superior Council. Thereby, a technical prioritization mechanism is determined if the solution to the demand is crucial for the country and is shared with the scientific community to start the research process, which lasts between 3 and 5 years until the technological solution is generated. The PECTIA document identified 275 (15%) of the agricultural demands [51].

The research process begins once the demand is prioritized by the Technical Committee of the SNIA Superior Council and is published on the platform that MADR has for this purpose. As soon as the entities that work in agricultural research and development are aware of the prioritized demand, they begin their internal processes to develop research and technological development, which lasts approximately 6 months. At the same time, MinCiencias can make public calls for proposals to provide solutions to the identified needs, and entities that meet the required requirements can submit their proposals, a process that also lasts six months on average.

Subsequently, the process continues with scientific research and field tests, which, depending on the complexity of the research, can take between 1 and 5 years.

Once the results are obtained and the technology is ready to be transferred to the end-user, work needs to be done on the transfer of the technology itself, which ranges from finding associations that are responsible for the seed multiplication to finding a commercial partner to producing the bioproduct, machine, software, or plant or animal variety. This process depends on the technology to be transferred.

Due to the delays, producers with greater monetary resources seek solutions to their technological requirements from private companies. These companies can solve the problem through their research and development department or seek, with foreign companies, agreements and solutions that take less time.

The levels and variables of the model are shown in **Figure 3**. At the top of the chart, we find the strategic resources, which are the factors affected by the end-results. These strategic resources are of a technical, human, and financial nature, for which we have: the demands prioritized by the SNIA Technical Committee, the research projects that will solve the demands, the SNIA entities working to solve the demands through their resources, the infrastructure, and the research staff that the entities must carry out the research.

Other resources include the agricultural extension agents, who are responsible for the technology transfer according to Law 1876 of 2017 [53], the products of Agricultural Science, Technology and Innovation (ASTI), the producers and their current dynamics, and the financial resources to carry out the ASTI activities and their transfer. ASTI products were divided into three categories: knowledge products, technology products, technological products and services.

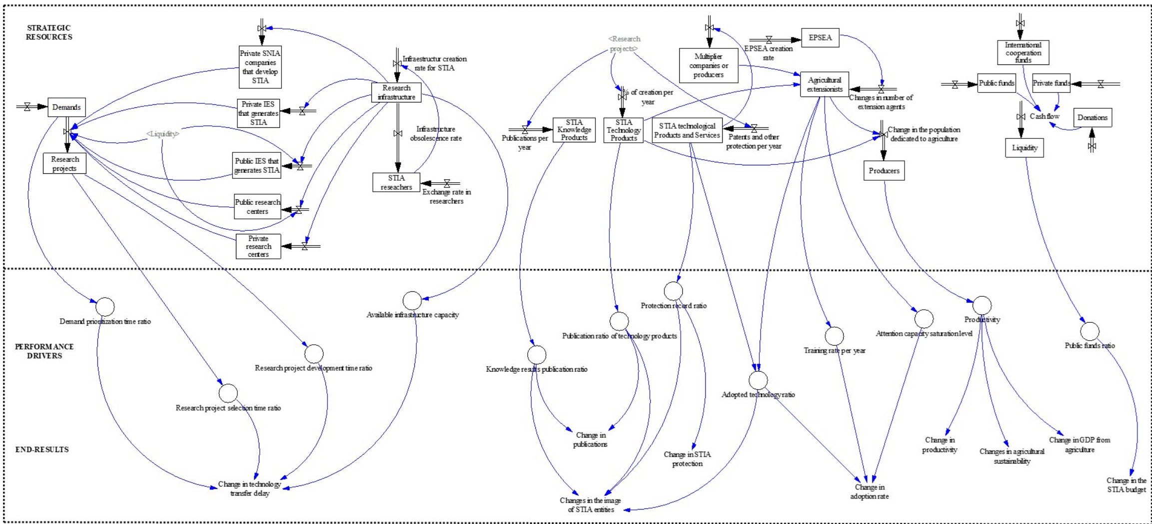

Figure 3. DPG chart of current agricultural technology transfer policy.

Knowledge products are the results of basic scientific research contributing to a better understanding of reality. These can serve as the basis for the development of new research and technologies, and generally, their main users are the scientific and academic communities.

Technology products are intangible results of applied scientific research that provide technological solutions systematically to the needs of the sector. Under this category, we can find technological recommendations, protocols, methodologies, and management practices.

Technological products and services generated from RDI initiatives include bioproducts, reproductive materials (both animal and plant), instruments, and tools designed to support agricultural production. These also encompass technological quality control services focused on agricultural and livestock products, as well as analysis and diagnostic services for animal, plant, mineral, and microbiological samples. Additionally, laboratory services tailored to the agricultural sector further enhance these offerings.

The middle box in **Figure 3** represents the performance drivers, which are made up of indicators that allow the behaviour of the variables to be measured. These are the intermediate results that are mandatory to reach the end-results.

The performance drivers could be grouped into three types, 1) those that allow controlling the delay that occurs in the transfer of technology; 2) those that measure the technologies that are transmitted, their transfer and adoption; and 3) those that have changed at the macro level of the country such as productivity, agricultural sustainability, and AGDP. The latter, in turn, would generate changes in funds that would allow us to achieve the virtuous circle set out in **Figure 2**.

The end-results of the model for agricultural transfer technology are based on Article 7 in the Law 1876 of 2017 [53]. These represent the changes in the transfer of technology delay that reduce the time to obtain science and technology products that agricultural producers need and are demanding.

The change in the image of the STIA entities is related to the change in the adoption rate. This image change will produce greater credibility and adoption of the technology created in Colombia by agricultural producers, as well as recognition of researchers at the national and international levels.

The changes in productivity will lead to improvements in agricultural sustainability and an increase in AGDP, bringing Colombia closer to achieving the SDGs. Additionally, these transformations will demonstrate to the government that investment serves as a powerful engine for development, thereby encouraging further investments in the agricultural sector.

4. Discussion

The review of technology transfer in Colombia allowed us to auscultate the past and present of public policy, see its evolution, and elucidate its components and issues. This retrospective vision allowed us to find that Law 1876 of 2017 [53] compiled and unified in a single document what was stated in different decrees, resolutions, and legal documents.

This review revealed that the system has failed to synchronize its efforts effectively, as public policy requires the implementation of political will to bring these efforts to fruition. Moreover, adequate resources and clear mechanisms are essential to ensure that all actors within the system benefit equitably. These mechanisms must avoid exclusions and power dynamics that disproportionately favor certain subsectors due to their negotiating power with the government.

This analysis also allowed us to be clear about the stakeholders and their relationships, depending on the SNIA subsystem in which they operate. It also highlighted the importance of their actions compared to what is expected to be achieved for a timely and efficient transfer of technology.

The virtuous circle of technology transfer demonstrates that delays pose significant risks by creating instability and oscillations [70]. Such delays can lead to an accumulation of unmet demands, ultimately overwhelming the system and rendering it incapable of addressing all the scientific and technological requirements requested by producers.

The analysis carried out on the delays allowed us to identify that they come from two different sources. The first of them is related to the time in which demand is transmitted from the territory until it is prioritized.

This delay represents a weakness in the system that could cause poor decision-making, because the prioritized technologies may no longer be as necessary as others at this time. This is true because the demands are dynamic and comply with the economic principle of local insatiability.

One of the possible solutions to the first delay is the improvement in the response capacity of the Technical Committee of the SNIA Superior Council, as well as the implementation of agile methodologies so that the response times are improved.

Thus, the existing mechanisms to know and prioritize the demands are not sufficient, since the agenda is updated every two years. To solve the delays, special mechanisms must be created to identify the demands that are emerging from the territory and generate an efficient, effective, and common knowledge form to prioritize demands and their order in the chain of follow-up and monitoring.

The second source of delay that was identified is presented in the transmission of the technology itself. Without technical assistance from the State, technology remains in the hands of private companies that, during their practice, only transfer the technologies from each one of the headquarters they work for.

The solution seemed straightforward: creating assistance programs by the state. Although such assistance was proposed in Decree 3199 of 2002 [71], it has not been effectively implemented. Consequently, agricultural extension is proposed as a solution to address this issue. This solution includes the legal establishment of extension services, mechanisms for financing, training, and registering extension agents and users. While the solution framework has been outlined, its implementation remains lacking.

To address this gap, agricultural extension agents and entities responsible for generating and disseminating technologies must be effectively coordinated and integrated.

The rural extension on the part of the state should be viewed as a dynamic and holistic process that strives to improve the integrated development of the agricultural and rural sector through several strategic drivers. Furthermore, a Rural Development policy should facilitate and support sustainable agricultural and rural development from different angles, such as a participatory approach that involves the local community to analyze and formulate solutions to the problems faced, allowing for the localization of these solutions and motivating change agents by empowering local leaders.

Additionally, the approach should incorporate a divisional framework that fosters multidisciplinary collaboration among fields such as agronomy, economics, sociology, and green science. These cooperative efforts should emphasize addressing rural challenges comprehensively while maintaining strong linkages between research institutions and the academic community.

This framework should be complemented by the use of IT for efficient information dissemination and coordination between producers and markets. Furthermore, creating innovation networks or bridges connecting producers, research and development entities, and technical personnel would facilitate the sharing of best practices and ideas. Finally, it is important to consider implementing virtual training programs as a means to reach remote communities effectively, ensuring equitable access to knowledge and resources.

Likewise, it is necessary to conceptualize the rural problems similarly by having different disciplines such as agronomy, economy, sociology, and environment with a participatory framework that makes synergy with universities and research centers. All this goes hand in hand with the use of information technologies for information dissemination and market production linkages, as well as the building of innovation networks where stakeholders such as producers, researchers, and extensionists exchange knowledge and experiences. Again, it is important not to forget that reaching out to distant populations is a very challenging task and that the deployment of virtual education programs would be appropriate for this purpose.

Besides this, rural technical assistance should not be limited to the provision of agricultural advice alone, but there is a need to provide credit facilities to small producers, and encouraging public expenditure support in the area is also necessary because it is not enough to come only to get information, but then there is also the need of acquiring new technologies.

When it comes to reforming and/or creating new public policies, it is imperative to keep going with the policies encouraging investments in sustainable practices and crop diversity in such a way that several public policies are integrated that support rural extension service actions with national and subnational policies to enhance the effective collaboration of different governmental bodies and non-governmental organizations to move resources and efforts efficiently.

The DPG model also revealed that the establishment of infrastructure for agricultural research development causes delays in the advancement of research and its dissemination to producers, particularly for organizations that receive public funds, as these sums of money fluctuate overtime.

5. Conclusions

The Dynamic Performance Governance (DPG) model highlighted key performance drivers that should be monitored and controlled to enhance the impact of technologies in the agricultural sector. These drivers enable improvements in technology transfer adoption, productivity, economic growth, and overall well-being.

It is important to note that the DPG presented in this paper does not aim to establish cause-and-effect relationships without sufficient data to model public policy. Instead, it serves as a qualitative modeling approach, paving the way for the potential integration of quantitative modeling in future analyses to further enhance decision-making.

From a system dynamics perspective, the current technology transfer policy aligns with a sigmoidal model. However, it can be characterized as a ”lazy system,” where proposed changes, though beneficial, require a significant initial impetus for implementation. This resistance stems from the system’s negative valuation of change, leading to its rejection.

Past rejections illustrate the significant challenge faced by the government: breaking away from entrenched habits within the system is essential to achieve the agricultural sustainability sought at both national and international levels.

The final consideration of this paper is a call to those in charge of executing the current policy of agricultural technology transfer, immersed in the National System of Agricultural Innovation, inviting them to review this model and the indicators for monitoring and follow-up. It is also a call to develop an inter-institutional work network to achieve the objectives established in Law 1876 of 2017 [53] and subsequent resolutions and decrees to prevent these efforts from being diluted, as has already occurred.

Author Contributions

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Conflict of Interest

All the authors made significant contributions to the document and those who agree with its content also agree to its publication and state that there are no conflicts of interest in this study. The authors report there are no competing interests to declare.

Appendix A

Table A1. Role of stakeholders in the agricultural sector by international, national, and subnational level.

	Policymakers and Decision-Makers	Advisory Offices	Funders	Coordinators	Knowledge & Data Generators	Knowledge & Results Transferors
International level						
CODEX ALIMENTARIUS		X			X	
Inter-American Development Bank (IDB)			X		X	
International Bank for Reconstruction and Development (IBRD)			X			
International Center for Tropical Agriculture (CIAT)					X	X
International Food and Agriculture Organization of the United Nations (FAO)		X	X		X	
International Fund for Agricultural Development (IFAD)			X			
International treaties		X	X			
International Seed Testing Association (ISTA)		X			X	
International Union for the Protection of New Varieties of Plants (UPOV)		X			X	
United Nations (UN)		X	X		X	
World Organization for Animal Health (OIE)		X			X	
World Trade Organization (WTO)		X			X	
National level						
Agrarian Bank (Banagrario)			X			
Agriculture Financing Fund (Finagro)			X		X	
Agustín Codazzi Geographic Institute (IGAC)					X	
Alexander von Humboldt Institute (IAvH)				X	X	X
Colombian Corporation for Agricultural Research (Agrosavia)				X	X	X
Colombian Mercantile Exchange (BMC)					X	
Colombian Agricultural Institute (ICA)		X		X	X	
Colombian Confederation of Chambers of Commerce (Confecámaras)		X	X		X	

Table A1. *Cont.*

	Policymakers and Decision-Makers	Advisory Offices	Funders	Coordinators	Knowledge & Data Generators	Knowledge & Results Transferors
Department of Social Prosperity (DPS)	X		X			
General Maritime Directorate (Dimar)					X	
Guilds		X	X		X	X
Institute of Hydrology, Meteorology and Environmental Studies (IDEAM)					X	
Internal Ministry (Min Interior)					X	
Ministry of Science, Technology, and Innovation (MinCiencias)	X		X		X	
Ministry of Agriculture and Rural Development (MADR)	X		X		X	
Ministry of Commerce, Industry, and Tourism (MinCIT)	X					
Ministry of Environment and Sustainable Development (MADS)	X				X	
Ministry of Finance and Public Credit (MHCP)	X		X			
Ministry of Foreign Affairs (Cancillería)	X					
Ministry of Health (MinSalud)	X				X	X
Ministry of Interior (MinInterior)	X					
Ministry of National Education (MEN)	X		X		X	
Ministry of Technology Information and Communications (MinTIC)	X				X	X
National Administrative Department of Statistics (DANE)					X	
National Aquaculture and Fisheries Authority (AUNAP)					X	X
National Corporation for Forest Research and Development (Conif)					X	
National Land Agency (ANT)			X	X	X	
National Learning Service (SENA)			X		X	X
National Planning Department (DNP)	X			X	X	
Rural Development Agency (ADR)			X	X	X	X
Rural Agricultural Planning Unit (Upra)		X			X	X
Special Administrative Unit for Restitution Land Management (URT)		X			X	
Special Administrative Unit of District Cadastre (UAECD)					X	
Superintendence of Industry and Commerce (SIC)					X	
Territory Renewal Agency (ART)			X		X	
Unit for Comprehensive Care and Reparation of Victims (UARIV)			X			
VECOL S.A.					X	X
Subnational level						
Autonomous Regional and Sustainable Development Corporations (CAR)						X
Chambers of Commerce			X		X	X
Entities providing the agricultural technical assistance service (Epsagro)						X
Governorates	X		X	X	X	X
Municipalities	X		X	X	X	X
Other Research Centers					X	X
Producers associations		X		X		X
Provincial Center for Agribusiness Management (CPGA)				X		X
Research Centers - Ceni´s (Cenicafé, Cenicaña, Cenibanano, Cenipalma, Cenicel)					X	X
Higher education institutions (IES) with programs linked with the agricultural sector			X		X	X

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