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MITIGATING RISK THROUGH R&D+INNOVATION: CHILE'S NATIONAL STRATEGY FOR DISASTER RESILIENCE

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ABSTRACT

With an annual average expense of more than $2,800 million USD, Chile leads the OECD countries with the largest percentage of the GDP spent in disaster losses per year (almost 1.2% GDP). This was the motivation of the Chilean President in 2015 to ask a group of experts to prepare a national Research, Development, and Innovation (R&D+*i*) strategy for disaster resilience. The strategy was developed by a group, called by the acronym CREDEN, and involved more than 80 experts representing different national stakeholders from the academia, public and private sectors, NGOs, and the armed forces. The work of CREDEN finished December 2016 and produced an R&D+*i* roadmap composed of five enabling conditions and 14 tasks. The implementation of this strategy demands a total investment of $914 million USD in 20 years, which is expected to have a benefit-cost ratio of 2.32, and annual savings of about $106 million USD. The first stage in this process is the design of a National Institute of R&D+*i* for Disaster Resilience (ITReND), which will oversee the implementation of the strategy. ITReND's design was completed in 2017 and its implementation is expected to begin in 2018. This strategy can be considered as an example of how to position R&D+*i* in the basis of public policy for disaster resilience. Both, the contents of this strategy and its implementation process, have unique aspects and may help guide other disaster-prone countries in their pursuit of larger resilience to the increasing occurrence rate of extreme natural events.

Keywords: disasters; R&D strategy; innovation policy; resilience; public policy

1. INTRODUCTION

According to the United Nations Office for Disaster Risk Reduction, UNISDR, disasters prompted by a natural agent have accelerated their rates of occurrence in the last 20 years, and they will continue to do so (UNISDR 2015a). The reasons are multiple. In the case of climatic disasters, global warming has increased the incidence of both floods and droughts around the world (UNISDR 2015a). In the case of geological disasters, there is a physical justification for their occurrence in clusters (Kanamori 1981). But, more than anything, it is the quick pace of urbanization and the increase of population and physical assets, especially in developing countries, the cause of the increase in the likelihood that a mere movement of the earth or a climatic event ultimately becomes a disaster. The challenge is becoming larger and larger as time goes on. In fact, according to UNISDR (2015a), between 2005 and 2014 at least 1.5 billion people have been affected by different types of disasters, with women, children, and people in more vulnerable conditions being disproportionately affected.
Among the most important and costliest recent events worldwide in the previous decades are the Indian Ocean earthquake and tsunami (2004), Hurricane Katrina in the US (2005), the Sichuan earthquake in

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China (2008), the earthquakes in Haiti and Chile (2010), and the earthquake in Japan (2011) (Munich RE 2016). These catastrophes have confronted the world with its most difficult reconstruction challenges since the aftermath of World War II (Fengler et al. 2008), providing a demanding test to check the current state of resilience of our nations.

In the case of Chile, in the last one hundred years the country has been subjected to more than 75 earthquakes Magnitude M_S 7.0 or larger, 11 large volcanic eruptions, 8 major wildfires, and 16 disasters caused by severe climate events, including droughts, flash floods, landslides, and extreme cold waves with heavy snowfall in the so-called "white earthquakes" (CREDEN 2016). Furthermore, only considering the last 10 years, the country has an impressive record, including some of the most devastating events of its history. Five volcano eruptions, four large earthquakes, three major fires affecting both urban spaces and wilderness, and two catastrophic landslides had struck the country since 2007. This includes the devastating M_W 8.8 earthquake and tsunami of central-south Chile in February 2010 that affected 69% of Chile's territory, more than 75% of its population, and left more than 370,000 buildings damaged, with a total amount of damage of $30 billion USD equivalent to 18% of the country's Gross Domestic Product (GDP) (de la Llera et al. 2017). Not surprisingly, among the countries of the Organisation for Economic Co-operation and Development (OECD), Chile is considered the most exposed to disasters of natural origin, with 54% of its population and 12.9% of its territory exposed to three or more types of hazards (Dilley et al. 2005). This also means that Chile has the largest percentage of annual GDP spent in disaster recovery among these countries (~1.2%).

However, this often dismaying situation has had some unplanned positive externalities. First, the country has gained experience in dealing with emergency situations. This is clear when we compare the amount of damage and casualties of the last events considered with those 100, 50, or 10 years ago. But, more importantly, the Chilean state has improved its resilience in terms of prevention, mitigation, and recovery capacities as well. Today, and especially after the major events of the last decade mentioned above, the issue has gained traction among the political, public, and private sectors. This has had important consequences. For example, after the earthquake and tsunami of 2010, the world was both shocked by the event and surprised by the low number of casualties and damage relative to the magnitude of the event. More recently, the earthquakes in north Chile in 2014 and 2015 confirmed this trend of increased resilience since the overall toll was an estimate of 21 deaths and around two hundred wounded people, along with a rapid economic recovery of the affected areas.

Overall, it is believed that Chile has been able to deal reasonably well with these disasters, simultaneously strengthening its institutional capacities throughout the process (Gil 2016). Figure 1 presents a summarized timeline with the seven most important Chilean earthquakes since 1900, and the most significant changes in the institutions and related codes as a result of these events. It is apparent that after every major earthquake in the history of the country, new state capacities have been developed in order to increase risk management in general and seismic regulation in specific (Gil 2016). For example, the earthquake of 1906 meant the creation of the first National Seismological Center, a pioneer institution in the country that advocated for seismic construction codes since its beginning. These codes saw light after another event, the 1928 earthquake in Talca, with the creation of the General Construction Law (OGUC). As presented in Figure 1, rules for construction in the country have been updated after almost every earthquake in its history. Housing policy is another area that has suffered major changes thanks to large earthquakes, a trend that starts with the creation of the Corporation of Reconstruction (CRA) after the 1939 event and continues until today in the form of the Ministry of Housing and Urbanism. And finally, in order to manage emergencies, since the great Chilean earthquake of 1960 in the lake district of Valdivia, the country has had a National Emergency Office (ONEMI), which will soon be transformed into the National Service of Risk and Emergency Management.

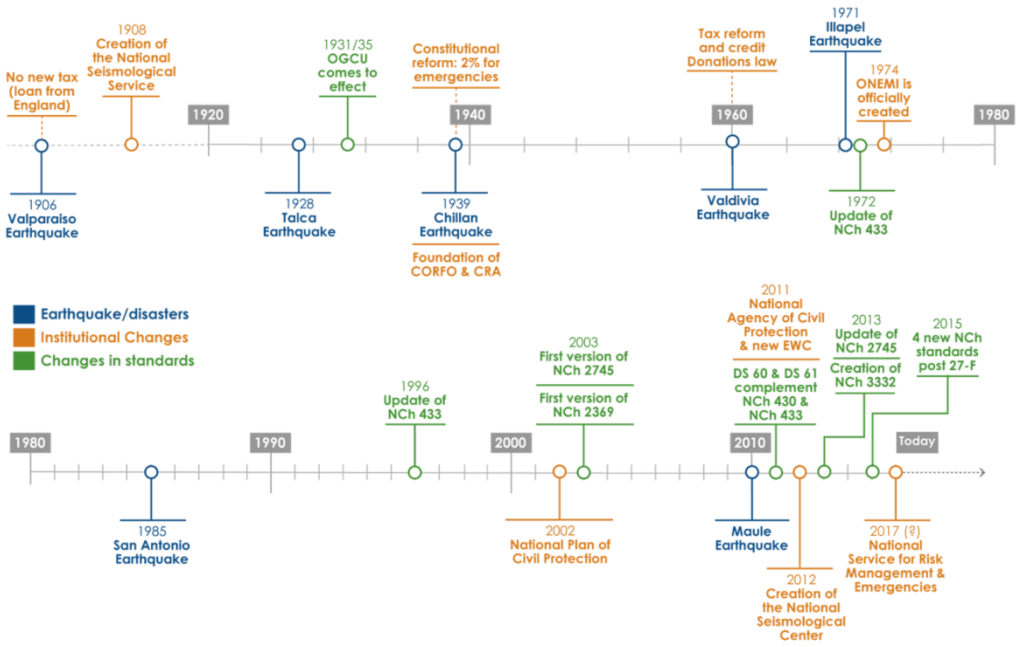

Figure 1. Most significant landmarks in the institutional legacy of Chilean earthquakes since 1906 (reproduced and translated from CREDEN 2016)

But not only earthquakes have generated institutional changes. Other examples abound, like the creation of the Southern Andes Volcano Observatory (OVDAS) after the 2008 Chaitén volcano eruption, the strengthening of the Hydrographic and Oceanographic Service of the Navy (SHOA) and the creation of a new Tsunami Early Warning Center as a result of the 2010 event, and new regulations and institutional changes under discussion now, such as the creation of a new National Forest Service, which replaces the current National Forest Administration unit, CONAF. In summary, it is true that the State has lost enormous resources in Chile due to past disasters but has also gained adequate training in dealing with these extreme events.

However, there is also a consensus that the route to resilience is not straight forward, and Chile is still in its beginnings; there is much to be done to adequately prevent, respond, recover, and mitigate from the devastating effects of these events. For instance, changes in urban planning and land use regulations, the continuous updating of building codes, and the development of insurance contracts that allow for a better economic recovery of the population are all examples of important needs. Although the country is considered to be well prepared to deal with its hazardous territory, it should also be acknowledged that there are significant challenges that still need to be addressed, or continuously come up, to achieve resilience.

In this context, and strongly influenced by the difficulties of the last 10 years in terms of disaster risk management and reduction in the country, the government created in 2016 the National Commission of Research, Development, and Innovation (R&D+*i*) for Disaster Resilience (CREDEN). The presidential mandate for this commission starts with the conviction that a key element of the risk management cycle rests in the development of relevant R&D+*i*. This is probably the most innovative aspect of the strategy and the corresponding public policy, since it will place research, development, and innovation at the core of the policy, which is rather unusual in Chile.

2. THE NATIONAL COMMISSION OF RESEARCH, DEVELOPMENT, AND INNOVATION FOR DISASTER RESILIENCE, CREDEN

2.1 The Origins of CREDEN

Two set of Chilean policies area relevant for the development of CREDEN. On one side, the Chilean *National Policy for Disaster Risk Management* constitutes a framework for Chile to create a comprehensive plan for prevention, response, and recovery after disasters (ONEMI 2014). The policy is linked with the Hyogo Framework for Action 2005-2015 and the Sendai Framework for Disaster Risk Reduction 2015-2030. Consequently, it recognizes that the State has a crucial role in reducing disaster risk and adding new responsibilities to local governments, the private sector, and academia, among other relevant stakeholders. Moreover, the Sendai Framework highlights the role of R&D+*i* for resilience in order to achieve the objectives presented by the framework. This has been incorporated in the Chilean National Plan in the form of a specific objective, to further develop the scientific capacities of the country (ONEMI 2016), for which the strategy deployed by CREDEN is an initial effort.

On another side, CREDEN's strategy is also connected with the Chilean *Strategy for Science, Technology, and Innovation*. The National Council of Innovation for the Development (CNID) is the state institution in charge of developing this strategy, which was delivered to the President in 2015. Its objective is to foster applied research and innovation in the country, defining a roadmap for the development of effective R&D+*i*. In this context, one of the recommendations made by CNID is to define priority areas that will guide the efforts in science, technology, and innovation (CNID 2015). Following this line of thought, the President announced in 2016 that one of the priority areas for the development of R&D+*i* in the country should be disaster resilience. Consequently, it can be highlighted that CREDEN resulted from a direct mandate of the Chilean President.

Therefore, the strategy developed by CREDEN is the product of a convergence of both policies, with a two-fold general objective: to use science, technology, and innovation to achieve a higher standard in physical and social resilience of communities exposed to natural hazards, and to make the Chilean expertise in dealing with disasters a differentiating innovative and sustainable advantage for the country. Finally, it was taken into account that Chile is not the only country searching for improved resilience. In this context, the reports *Disaster Resilience: A National Imperative* (NRC 2012) and *National Earthquake Resilience: Research, Implementation and Outreach* (NRC 2011), developed by the National Research Council of the United States, were of great importance for the development of this strategy.

2.2 Operation of CREDEN

The motivation for CREDEN was to make Chile a more resilient country through R&D+*i*. The question that guided CREDEN's work was: what would it be needed, in terms of R&D+*i*, to increase the country's resilience to extreme natural events? For this purpose, the scope of the commission was narrowed down to only include the case of low-probability extreme events with large social, physical, environmental, and economic impact. In this context, it focused only in six types of hazards, corresponding to the most relevant threats to Chile: earthquakes, tsunamis, volcanic eruptions, landslides, extreme weather phenomena (e.g. droughts and flash floods), and wildfires. In addition, the strategy recognizes the complex nature of these phenomena and considers their interdependency and multidimensional nature, which is expressed in different phases of the risk management cycle.

The meetings of the Commission lasted a full year, from January through December 2016. Four large goals were tackled by CREDEN in the strategy: (i) to improve the physical and social disaster resilience of the country; (ii) to develop cost-effective tools to assess the response, risk, and resilience of physical and social systems; (iii) to deepen the understanding of the physical processes associated with the natural hazards as well as our physical and social exposure; and (iv) to transform the concern of disasters of natural origin into a sustainable innovative advantage to develop the country. A Central Committee (Board) and four Subcommittees were formed to address different dimensions of the strategy. The Board was formed by 27 experts from the academy, armed forces, industry, and the political sector. The work of the Subcommittees allowed including more experts to the development of the strategy; on average, each Subcommittee was integrated by 15 permanent members, but, overall, more than 80 experts

participated in all of them. Additionally, the work of CREDEN was supported by two teams, a technical staff led by the President of CREDEN, and an executive group under the supervision of CNID.
Each Subcommittee had the mission of delivering the strategy to tackle one of the four large goals: (i) *Resilience*; (ii) *Response and Risk Assessment*, (iii) *Physical Processes and Exposure*; and (iv) *Innovation for the Development*. The *Resilience* group focused on proposing R&D+*i* recommendations with a strong social emphasis, i.e., bringing communities and people into research and taking advantage of their local knowledge and culture. The second group, *Response and Risk Assessment*, placed an emphasis on two aspects: first, on the importance of developing front-end stochastic and simulation tools for risk and resilience evaluation; and second, to properly transfer these results into the communities and decision-makers. The group of *Physical Processes and Exposure* focused on designing a roadmap to better understand the processes associated with the natural physical phenomena leading to disasters, as well as the actual physical exposure. The tasks were tackled from the perspective of what scientific knowledge is needed to improve the risk management and the resilience of communities to disasters. Finally, the Subcommittee of *Innovation for the Development* approached its goal by identifying the singularity of Chile in terms of its large geographical diversity and high severity of natural hazards across its territory, and transforming it into a sustainable competitive advantage worldwide in the form of a technological industry of products and services.
To provide a global perspective into the strategy, CREDEN was accompanied by an International Board of Experts (IBE) in disaster resilience, total of six, which helped in the assessment of the progress of the strategy and provided feedback according to their local and global experiences. The IBE visited Chile and met with the Board of CREDEN to criticize and suggest specific notes for the strategy. Additionally, they gave an open seminar in Santiago to present their research and professional work to the Chilean community. The work with the IBE was of extraordinary importance to build the final strategy, and it is fair to say that some ideas presented in the strategy came directly from this discussion.

3. THE R&D+I STRATEGY FOR DISASTER RESILIENCE

The strategy was presented to the President on December 20th, 2016. The final document, *Toward a Disaster Resilient Chile: An Opportunity* (CREDEN 2016), contains the roadmap to increase resilience to disasters of natural origin in Chile through R&D+*i*. It was structured around fourteen tasks describing the medium- and long-term guidelines for science, technology, and innovation on disaster resilience in the country. They are accompanied by a set of five enabling conditions to be developed to provide the country with the adequate institutional structure, resources, and capacities to implement, develop, upgrade, and sustain the strategy in time. The elements of the strategy are summarized in Table 1.

Table 1. Summary of the elements of CREDEN's strategy (adapted from CREDEN 2016).

Purpose	To make Chile a more resilient country to natural risks by means of original R&D+*i* responses that will have a positive impact on its development			
Core values	• R&D+*i* of excellence, which is sensitive to physical and social contexts • A commitment with the quality of life and well-being of the exposed people and communities • An aspiration to achieve natural risks equity for the population • The promotion of responsible and significant participation of all stakeholders • The generation of a resilient culture for Chile • R&D+*i* that supports effective governance in natural risks management			
Dimensions	Social dimension of resilience	Dimension of risk simulation and management	Physical dimension of natural hazards and exposure	Dimension of projection for development

Tasks	T1: Social resilience to disasters T2: Resilience of lifelines and critical infrastructure T3: Demonstrative projects on regional and community resilience	T4: Scenarios of disasters of natural origin T5: Simulation of losses, and risk and resilience assessment T6: Assessment and improvement of the resilience of the built environment	T7: Physics of the natural hazards processes T8: National monitoring and reporting system for natural hazards T9: National models of natural hazards T10: Early warning systems T11: Predictive models for disaster response operations	T12: Public goods and policies to activate the demand for innovation in disasters resilience T13: Next-Generation of technologies, sustainable materials, components, and systems T14: New applications of ICCT* and other enabling technologies
Enabling conditions	• Institutional framework for R&D+*i* in disaster resilience • Data and information integration • Development of advanced human capital on resilience • Development of infrastructure for scientific discovery and innovation in resilience • Scientific outreach and dissemination			

**ICCT: Information, Control, and Communication Technologies*

Because CREDEN was a multidisciplinary and multi-sectorial endeavour, one of the first tasks of the commission was to generate a common definition of resilience, shared by all, and which reflected the different dimensions of the concept while representing the ideas that the group had on the topic. The adopted definition was the following: "Resilience refers to the capacities of a system, person, community, or country exposed to a natural hazard to anticipate, resist, absorb, adapt, and recover from its effects in a timely and effective manner, and to achieve the preservation, restoration, and improvement of its structures, basic functions, and identity" (CREDEN 2016).

3.1 The R&D+i tasks

One of the main concerns CREDEN had when defining the tasks was to outline a strategy where the R&D+*i* was driven directly from real community needs and the observed consequences and challenges arising after the recent events in the country, instead of preconceived research agendas coming from academy and other research institutions. This approach allowed positioning different subjects with low presence in academia but with large impact in the resilience of the country, such as understanding, assessing, and improving the operational continuity of different industries.

The fourteen tasks tackle four different dimensions of disaster resilience, including the creation of knowledge and its translation into technological development of goods, services, and devices (see Table 1). Regarding the social dimension of resilience, three tasks describe the interdisciplinary path to understand social vulnerability in a context of disasters of natural origin, drivers for resilience at the individual and organizational levels, and the capacities to anticipate, mitigate, prepare for, respond to, and recover from disasters. An important emphasis was also put in the thorough comprehension of resilience of critical infrastructures and lifelines and their interaction with all other social systems. Additionally, the development of demonstrative pilot projects is considered to increase awareness in the population, but also to properly assess the effectiveness and impact of the implementation of this strategy.

The strategy also decomposes the dimension of risk and simulation management in three tasks. Here, the focus is on the quantitative perspective of the problem and the calculation of risk and resilience in complex system multi-hazard environments. This dimension includes the development of multi-hazard scenarios of disasters of natural origin comprising knowledge from physical and social sciences and engineering into real geographical and social contexts. Scenario-driven research should feed the development of models and simulation tools to estimate the expected physical, social, economic, and

environmental losses. Additionally, an emphasis is placed in probabilistic risk and resilience assessment, focusing on lifelines, critical and strategic infrastructure, networks, and communities. The upgrade and retrofit of the built environment is also considered through an extensive R&D+*i* program which will strengthen and better prepare it for future events.
The third dimension of the strategy corresponds to the physics of the natural processes that lead to the hazard, and the understanding of the evolution of the physical and human exposure in time. Thus, five different tasks outline the need for advancing knowledge on the generation, prediction, propagation, interrelation, and the physics of the processes governing natural events, with an emphasis in multi-hazard configurations. The other tasks describe the need for developing an improved and integrated national monitoring system for these hazards, adequate early warning systems for the Chilean context, reliable and high-resolution national models for hazards, and predictive models for disaster response.
Directly addressing the large goal of creating a new technological industry for disaster resilience, three tasks tackle the dimension of projection for the development of the strategy. These tasks acknowledge the need for activating the demand for disaster resilience innovations in the public and private sectors and proposes non-conventional instruments to facilitate their incorporation in areas with large impact in the country's resilience. An emphasis is placed in the use of new information and communication technology applications and solutions, control technologies, and in the development of new technological solutions for increasing community resilience throughout the country.

3.2 Enabling conditions

Across the work of CREDEN and its Subcommittees, several structural deficiencies and collective collaboration problems were identified in the Chilean R&D+*i* ecosystem. These corresponded to major structural weaknesses decreasing the impact of the local research and preventing effective transfer of its results to public goods, services, and technologies. This way, five enabling conditions were defined to complement the fourteen R&D+*i* tasks and address these issues, thus providing a strong basis to sustain and implement the strategy in time. Recognizing the structural deficiencies hindering the development of high-impact R&D+*i* in disaster resilience in Chile, these five enabling conditions are key in the success of the strategy.
The enabling conditions are the following:

- **Institutional R&D+*i* framework for disaster resilience**: consists on developing the adequate institution to host, articulate, and develop the strategy consistently in time, in the form of a new national public institute of R&D+*i* for disaster resilience (see Section 4).
- **Integration of data and information**: consists on the development of the National Spatial Data and Information System for R&D+*i* in disaster resilience, thus addressing the lack of integrated data and first-class information which strongly affects Chile's international image as a privileged natural laboratory for the comprehensive study of natural hazards and disasters.
- **Advanced human capital in resilience**: consists on developing the necessary human capital specialized in disaster resilience to further support and develop the R&D+*i* outlined by the strategy. This will take the form of new special scholarship programs for prioritized areas, the creation of double doctorates programs with participation of local and international institutions devoted to research in disaster resilience, and creating a special postdoctoral program of applied research on disaster resilience that includes technological and innovation centers and highly specialized industries.
- **Infrastructure for discovery and innovation in disaster resilience**: consists on creating a distributed national network of experimental facilities with at least one world-class laboratory per discipline, giving access to all researchers and developers within the R&D+*i* network. The following laboratories were proposed: (i) earthquakes and volcano hazards and response of the physical infrastructure; (ii) climate change and sustainability; (iii) tsunamis and cryospheric hazards; (iv) social vulnerability and resilience; and (v) manufacturing, sensorization, and information, control, and communication technologies (ICCT) for resilience.
- **Public outreach and scientific dissemination**: consists on ensuring that the research and innovation generated reach decisions-makers and communities adequately through the development of specific channels for communication between the scientific community and the general public.

3.3 Budget and expected impact

The budget was projected for a timeframe of twenty years, in US dollars of 2016. The average cost of implementing the strategy is estimated in $45.7 million USD annually, for a total cost of $914.2 million USD. Of this total, $315 million USD would be allocated to the enabling conditions, and the remaining $600 million USD to the fourteen tasks of the strategy.

To assess the impact that the implementation of the strategy could have in Chile, a Cost-Benefit ratio of 2.32 was calculated. The details of the calculations can be found in CREDEN (2016) and are based on an analysis made by the Multihazard Mitigation Council in 2005 and on the expected losses data provided for Chile in the Global Assessment Report on Disaster Risk Reduction (GAR) (UNISDR 2015b). This 2.32 Cost-Benefit ratio means that, in present terms, for each dollar invested in the strategy, the country would save 2.32 dollars in hazard related losses. To accomplish these savings in time, one of the main challenges for the implementation of the strategy is the transfer of knowledge. For this reason, the enabling activity related to outreach and dissemination plays a key role in the success of achieving larger resilience.

4. IMPLEMENTING THE STRATEGY: THE DESIGN OF THE NATIONAL INSTITUTE OF R&D+I FOR DISASTER RESILIENCE

The involvement of different groups of stakeholders in CREDEN led to immediate actions to implement its R&D+*i* strategy. Thus, a 1-year fund from the Production Development Corporation (CORFO) was raised to work in the detailed design of the National Institute of R&D+*i* for Disaster Resilience, in short ITReND. The Institute arises from the first enabling condition of CREDEN's strategy (see Section 3.2), with the goal of overseeing the implementation of the rest of the strategy in time.

The project of designing ITReND was led during 2017 by CREDEN's President with the collaboration of a group from Pontificia Universidad Católica de Chile and the Center for Mathematical Modeling at University of Chile. The project was overseen by CNID and the Ministry of the Interior and Public Safety. The institutional design of ITReND included the following tasks: (i) definition of its roles and functions; (ii) map of the existent capacities for R&D+*i* in disaster resilience in Chile, including people, infrastructure, and networks; (iii) perform a national and international benchmarking; (iv) define an organizational and governance model; (v) define a set of performance indicators; and (vi) develop a strategy and policy of intellectual and industrial property.

4.1 ITReND's value proposition

The focus of ITReND was defined as solving the set of structural collective coordination failures in the disaster resilience R&D+*i* ecosystem. One of the most significant of these faults is the difficulty of coordination that affects the interactions among all actors of the system –academia, industry, public sector, and civil society. This affects the ability of the system to produce synergies, harming its overall performance and production of goods. An important manifestation of this problem is the deficient cross-disciplinary and interdisciplinary collaboration between national institutions, both in the academy, and in the public and productive sector. This hampers the development of innovations and does not take advantage of the benefits arising from the interaction of different research groups. In addition, international collaboration is fragmented in different centers throughout the country, making it difficult to establish a common vision and long-term goals with effective interactions on strategic issues that directly impact the development of the country. This lack of coordination triggers an inefficient use of the scarce existing resources, be they financial, human, or infrastructure.

Likewise, investment in innovation programs is difficult due to the incipient size of the market associated with technological solutions in this area. This is partly due to the absence of a public demand capable of generating the growth of the industry, a limited internal demand for innovative solutions, and the absence of an active capital market of insurance and reinsurance for projects designed and operated in a context of natural hazards. Additionally, there are problems of disaggregation and disconnection in the value chain of technology transfer in the field, with few links between scientists, experts, practitioners, and innovators capable of strengthening and energizing this chain.

Moreover, the system is affected by the classic problem of missing markets for public goods. The main objective of the results of the R&D+*i* tasks proposed by CREDEN's strategy is the generation of knowledge to increase disaster resilience. This knowledge, and subsequent transfer to the community, comply with the two basic principles that define a public good: non-rivalry and non-exclusion. Programs leading to increased resilience in the country guarantee greater opportunities for safety and prevention of disasters, benefiting the entire population, without rivalry in their enjoyment. This results in a low availability of private resources for the financial support of such a system, except for well-defined niches, such as operational continuity in certain industries. In a country like Chile, constantly confronted with these events, it is in the public interest that the state provides resources and incentives to maintain an active R&D+*i* strategy leading to the development of scientific knowledge and technologies to improve the preparation, response, recovery, and mitigation capacities, in addition to constantly promoting a culture of resilience.

In this context, three axes of strategic action were defined for ITReND. Axis I refers to the **Intelligent Articulation of the R&D+*i* network**, and is associated with the process of coordination of the capacities and resources for R&D+*i* in a coherent and efficient manner around CREDEN's strategy. The second axis deals with the **Capacities for R&D+*i***, and is associated with generating and building the basic tools necessary for the development of first-level R&D+*i* in Chile; this axis encompasses three of the four enabling conditions identified by CREDEN (see Section 3.2). And Axis III, which is related to **Transfer and Dialogue with Society**, associated with the process of synthesizing, disseminating, and transferring the results of R&D+*i* toward society through a permanent dialogue between the different actors of the R&D+*i* ecosystem and communities, and translating them into goods such as technologies, services, and public policies.

The three axes for strategic action in ITReND gather all the elements in CREDEN's strategy, namely the R&D+*i* tasks (see Section 3.1) and the enabling conditions (see Section 3.2). To facilitate the coherence between CREDEN and ITReND, each action axis is composed of different strategic functions as described in Table 2.

Table 2. ITReND's value proposition is spread into three strategic action axes and eight strategic functions.

Strategic Axis	**Goal**	**Strategic Function**	**Description**
Axis I: Intelligent articulation	Coordinate the capacities and resources for R&D+*i* in a coherent and efficient manner around CREDEN's strategy	Articulation of the R&D+*i* network	Coordination of the R&D+*i* network according to CREDEN's strategy
		Intelligence and establishment of guidelines	Intelligence and technological surveillance allowing ITReND to deliver long-term guidelines for larger resilience. Considers: (i) mapping the needs, concerns, and interests of the different stakeholders of the R&D+*i* system, and (ii) the permanent updating CREDEN's strategy
Axis II: Capacities for R&D+*i*	Generate and build the basic tools and capacities necessary to develop first-level R&D+*i* in Chile	Data infrastructure	Development and implementation of an open data and information infrastructure to promote R&D+*i* for resilience
		Advanced human capital	Development and insertion of the professionals necessary to implement and sustain the strategy over time
		Experimental infrastructure	Development and coordination of the infrastructure network for discovery and innovation for resilience

Axis III: Transfer and dialogue with society	Synthesize, disseminate and transfer the results of R&D+*i* to the society in the form of technologies, goods, and public policies, while establishing a continuous dialogue with the communities	Development of public policies	Development of initiatives that incorporate the knowledge generated through the R&D+*i* in the process of creation of public policies. This includes the generation and renewal of laws and regulations that regulate the actions of private actors and of public institutions
		Linkage with the society	Connection with the different social actors that ensure both the active citizen participation in the generation and transfer of knowledge and the technologies that are developed, as well as the enthusiastic incorporation of the issue of resilience in public discussion
		Development of new solutions and industry for resilience	Promotion of the generation of a new industry of innovative technologies, materials, and services associated with disaster resilience

4.2 The new institutional framework in Chile

It must be taken into account that the new institute will face institutional challenges in the country. In the first place, the 2017 presidential election of late December may certainly have an impact in the Institute's future, since the new President will have to make important decisions about continuity and strengthening of this type of projects. Unfortunately, the topic of science and technology has been almost completely absent from the political discussion and no candidate committed to a full plan for disaster risk management either. This creates a halo of uncertainty that ITReND will certainly have to consider during the next year.

Also, there are two bills that are under discussion right now in Chile's parliament that directly affect ITReND and could have a positive impact in its development. First, there is a project to upgrade the current ONEMI into a National Service of Risk and Emergency Management. This does not only mean greater resources for this institution but also shows an evolution from emergency and disaster management to a comprehensive program on disaster risk reduction. Also, the project contemplates the creation of a Committee of Experts to advice the President in topics related to risk and disasters that should be integrated by six relevant scientists from different areas of knowledge. This also shows that the law contemplates a change of paradigm in the country, one where ITReND can easily find a place to develop.

The second bill under discussion today, which is enormously relevant for the development of ITReND, is the project for the creation of a Ministry of Science and Technology. Nowadays, the strategy of scientific development and research in Chile is in the hands of a Commission (CONICYT) that was created in 1967 within the Ministry of Education. This institution has a budget of $305,491 million pesos (~$466 million USD) to fund research and development in the country. However, it is a fact that Chile has an enormous gap between this amount and what it is really needed to invest in R&D+*i* to become a developed country: only 0.38% of Chile's GDP is invested in this area, versus a 2.38% average among OECD countries. Thus, the new project under discussion intends to create a new institution that can manage and execute instruments for the promotion and development of science and technology. In this context, and assuming both projects will have a positive ending, it is clear that ITReND is crucial in the development of both policies.

Despite ITReND still has not been formally created legally, it has had an important influence in the country's R&D policy. During the process of designing the Institute, and highly influenced by CREDEN's strategy, CONICYT has announced the creation of its first fellowship in prioritized areas to study masters programs abroad. One of the three areas for these fellowships is disaster resilience, together with water resources and digital transformation. With 75 available scholarships, this constitutes a major achievement of CREDEN and a first step in the implementation of the enabling conditions

programs (see Section 3.2), which will certainly have an important effect in the construction of the basis for increasing resilience in Chile through R&D+*i*.

5. CONCLUSIONS

This paper presented Chile's recent effort to develop a comprehensive R&D+*i* strategy for disaster resilience. This endeavor started with the conformation of a multi-sectorial national group of experts, CREDEN, by mandate of the President. The work of CREDEN showed that resilience is a challenge that must be confronted trough a collaborative effort. Disasters are a shared concern that benefit enormously from cross- and interdisciplinary perspectives. Also, it was shown that disasters can be looked at also from a more positive viewpoint, say as an opportunity for growth and development. In this context, Chile was seen as a "natural laboratory" for R&D+*i* in resilience. Consequently, a strategy for taking advantage of this situation has been created. The strategy aims to two major goals. On one side, to provide the inputs needed to improve the scientific work and technology that would allow Chile to be a more resilient country, thus reducing the important impact of disasters. On the other side, to transform Chile into an innovation hub for disaster resilience based on its singular conditions. To this end, five enabling conditions were identified, and 14 specific tasks were defined.

Additionally, the work of CREDEN produced a consensus about the lack of funding, support, and the institutional framework needed for the implementation of the strategy. This awareness led to raise funding for the implementation of the first of the enabling conditions; this is, the creation of a national institute to oversee the development of the strategy. Thus, the experience of CREDEN continued with the design of ITReND, the National Public Technological Institute of R&D+*i* for Disaster Resilience. As a meta-institution meant to provide a long-term plan for R&D+*i* in risk and resilience to disasters, ITReND will coordinate the existing capabilities of the country toward the goals stated by CREDEN's strategy, and further develop the conditions to improve and sustain it in time.

This experience can be considered as a case-study to show how science and technology can play a significant role in the development of future public policy aimed to public goods. A good example is the change in purpose-oriented scholarships produced this year in Chile. The Chilean example can serve and encourage other disaster-prone countries to position science, technology, and innovation in the core of public policies in their countries, which in this case aim to increased resilience.

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