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Applying knowledge governance to understand the role of science in environmental regulation: The case of arsenic in Chile

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ABSTRACT

The relationship between scientific knowledge and decision-making surrounding environmental issues is complex and represents a flourishing area of scholarship and practice. However, a sense of frustration persists regarding efforts to increase the use of science for decision-making. Regulations of copper smelter arsenic emissions developed in Chile during the 1990s represent a successful example of science informing policy making. The case involved production and use of local science in contrast to the common practice of copying international ambient standards.

In this paper, we investigate arsenic regulation in Chile in the 1990s and focus on the role of the major science intervention during the process, project FONDEF 2-24. The case is examined through the lens of knowledge governance (van Kerkhoff and Pilbeam, 2017). This theoretically-oriented approach guides our critical reflection on the relationship between knowledge and policy making, taking into consideration the formal and informal rules that shape the intervention and the underlying social and cultural patterns. The success of the science intervention's influence on policy is better understood with such a perspective.

We expand the knowledge governance approach by scrutinizing the relations of coherence between levels of analysis to assess their alignment. The approach could be helpful for studying other cases, particularly at times when a new field of policy is emerging.

1. Introduction

Despite advances in explaining how environmental policy decisions are made and what is and should be the role of science in policy making, a need for deeper understanding remains (Kirchhoff et al., 2013; Clark et al., 2016). The knowledge gap is greater in Latin America and other regions of the global south, where little region-specific scholarship has been developed.

A common strategy of developing countries for using science in environmental policy making has been to borrow and copy from the North, for example, by replicating standards proposed by the World Health Organisation (WHO) or the US Environmental Protection Agency (EPA). Adopting international standards saves the cost of developing local research and conforms to global norms. In Latin American history, it has been common to see science as an imported activity (Medina et al., 2014). Also, the scientific community is often small and without enough capabilities to offer responses to the state needs (Barandiarán, 2013).

In contrast to common practice, local science did inform arsenic regulation in Chile in the 1990s. During that decade, the context of a post-dictatorship developing country presented multiple social and political challenges and extreme socio-economic inequality. Environmental policy issues became a clear area of policy making in Chile. Using the definition of Massey and Huitema (2013, 2016), the policy field of environmental management emerged supported by regulations, formal institutions and technical expertise.

In this paper we examine why a purposely developed local research effort was effectively used to develop arsenic regulation, using a knowledge governance perspective (van Kerkhoff and Pilbeam, 2017, 2015; van Kerkhoff, 2013). Specifically, we focus on the largest project in Chile in which science informed arsenic regulation: the FONDEF 2-24, a project developed from 1994 to 1996 as a deliberate intervention with the goal of providing scientific evidence to promote and orient arsenic regulation. Applying the knowledge governance approach reveal the complex interaction among the underlying cultural patterns, the institutions and the intervention of science in policy processes.

The paper begins by introducing the topic, providing the theoretical framework (Section 2) and describing our methodology (Section 3).

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Section 4 describes the results for each of the three layers of analysis considered by the knowledge governance approach: the underlying civic epistemology, the knowledge system, and the intervention itself. Section 5 discusses the implications of applying a knowledge governance framework to a Latin American case study, and Section 6 concludes.

2. Theoretical approach: Knowledge governance for Latin America

Knowledge use in policy decisions has been a permanent topic within environmental studies (Cash et al., 2003; Lemos et al., 2012; Kirchhoff et al., 2013, 2015; Clark et al., 2016), most often with a focus on research practices facilitating policy action (Kates, 2011; Miller, 2011). However, recent work (e.g. Miller, 2013; Miller and Neff, 2013, Van Kerkhoff and Pilbeam, 2017) suggests that a more nuanced understanding of the role of environmental science in policy making requires greater attention to social and cultural context along with deeper understanding of the role and practice of scientists within this context. It is a call for bringing sociological approaches into environmental studies, in particular to learn from the critical perspectives of the science, technology and society studies (STS), for example the contributions of Jasanoff (2004, 2005, 2009, 2012) and Jasanoff and Kim (2015). Our work aligns with efforts in this direction.

As actors within the knowledge system, scientists produce and reproduce culture and define disciplinary research trajectories (Jasanoff, 2011), interpreting science-policy goals and values, and integrating these within research agendas. In order to understand the role of science in the policy making process, environmental science-policy scholars need to unpack the social processes involved in defining research agendas, and the processes by which research results contribute to policy outcomes (Miller and Neff, 2013).

The concept of knowledge governance proposed by van Kerkhoff and Pilbeam (2017) builds upon previous research (van Kerkhoff, 2013) and empirical work (van Kerkhoff and Pilbeam, 2015). It offers a conceptual framework for understanding scientific interventions, integrating views from environmental sciences and critical perspectives from STS, which have rarely overlapped (MacMynowski, 2007).

Knowledge governance considers the underlying framework of rules and conventions within which knowledge processes take place. This approach requires a shift "from understandings of knowledge as an *input* to governance of environmental issues … to understanding knowledge as *subject* to governance" (Kerkhoff and Pilbeam, 2017: 32). The framework provides a middle ground where the instrumental goals of environmental science and the reflexive efforts of the critical sciences can complement each other. Fig. 1 depicts the proposed layers of knowledge governance analysis.

These three layers of analysis range from the most evident science-policy interventions to the often invisible, tacit rules underlying the social interactions embedded in knowledge systems and civic epistemology.

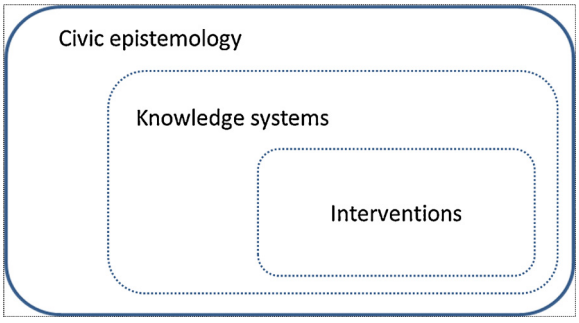

Fig. 1. Conceptual framework of knowledge governance.
Source: Authors, based on van Kerkhoff and Pilbeam (2017:32).

'Interventions' describe goal-oriented actions directly shaping science-policy relationships. Investigations on interventions may be case studies aimed at learning about the particular strategies used for communicating science and the boundary work done throughout the project to close the science-to-action gap. The objective of these studies is often to extract lessons for good practice. The project FONDEF 2-24, for example, was analysed from that perspective by the Global Development Network (GDNet), an international cooperation project, aimed at developing understanding on how Southern research can contribute to development. It named the project FONDEF 2-24 as one of the ten best practices in their program of science-policy interface, from which they extracted lessons for bridging the gap between science and policy making (Brown, 2014).

'Knowledge systems' refer to the institutions providing a framework for the relationship between science and action; these may be legal bodies and formal or informal rules within the science-policy arena. The knowledge systems' approach (Cash et al., 2003) focuses on institutional structures fostering or inhibiting relations between science and action. In this view, science is effective when it demonstrates salience, credibility, and legitimacy. *Salience* refers to the relevance for the action taker, while *credibility* indicates how scientifically sound it is, and *legitimacy* considers whether it is fair to all stakeholders involved. These characteristics are observed in institutional and organisational arrangements and in researchers' practices for communicating their scientific findings and translating them into lay terms, as well as in the work of boundary organisations, acting as brokers, for example between scientists and political actors. Knowledge systems move beyond a particular intervention to reflect on the modes of governance shaping research programs. It has been an influential approach in environmental science, giving place to numerous studies investigating science-policy relationships (e.g., Lofmarck and Lidskog, 2017; van Kerkhoff and Szlezák, 2016; Cornell et al., 2013).

'Civic epistemology' represents a broader concept involving social, political and cultural rules governing which practices are possible within specific historical circumstances. Jasanoff (2005) developed the concept while comparing the "ways of knowing" about the risks and harms of controversial life sciences in the U.K., Germany and the U.S. Jasanoff proposes six aspects of analysis, which van Kerkhoff and Pilbeam (2017) translated into questions to be asked. The areas of inquiry to characterize civic epistemologies in a field of study are: i) the observed styles of public knowledge making, ii) the ways knowledge is made accountable, iii) the foundations for expertise, iv) the demonstration practices of knowledge effectiveness, v) the transparency of expert work, and vi) practices for securing objectivity. Civic epistemology is an approach focused on features of societies generally related to cultural patterns, mentalities, and collective behaviours. It provides an entry into the underlying cultural and political patterns supporting institutional arrangements, complementing the focus on action-oriented interventions and knowledge systems of environmental science frameworks.

Knowledge governance integrates these previous approaches and positions interventions within institutional rules and organisational practices, uncovering the socio-cultural patterns that constitute civic epistemology. It examines the conformity of interventions with existing rules and ways of knowing.

In this paper, we systematically apply the three layers of the knowledge governance framework (civic epistemology, knowledge systems and intervention) to the case study of airborne arsenic regulation in Chile. Our aim is to try out theory in practice (Bourdieu and Wacquant, 1992).

Although we focus on Chile in the 1990s, insights can be applied to other cases. For example, relevant social and cultural changes occurred in the 2000s in Latin America and resulted in an increased role of civil society in environmental policy making (Castro et al., 2015). Effective climate change policies will require the integration of these shifting roles. The potential emergence of climate adaptation as a policy field

over the next decade will similarly be framed by social change.

3. Methodology: Case study and methods

The arsenic case study represents an early experience of the science-policy relationship under a new regulatory system where scientific knowledge was legally assigned a place within environmental policy making. We use a case study and a wide range of process tracing to explain the phenomena (Ragin and Becker, 1992) and to assess theory (George and Bennett, 2004).

A knowledge governance perspective implies a focus on actors and their interpretations of knowing, doing and learning. It considers knowledge as co-produced during interactions among actors and between actors and their historical circumstances (van Kerkhoff and Lebel, 2016). In specific terms, we focus on interactions within the domain of scientific and technical knowledge. We pay special attention to the relationship between the different levels of analysis. Our analysis includes a discussion on whether we observe coherence or divergence between the research components; we assess alignment among actors and levels of analysis.

First, we gathered academic literature and interview data on the case and its context to identify relevant actors, their roles in the regulatory process, and the interactions among actors in the sphere of science and technical knowledge. This preliminary inquiry resulted in a basic chronological narrative of the process and main actors.

Key actors were involved in defining or applying the rules for regulating arsenic air pollution. These actors included: public servants from the then newly created environmental government authority, the National Commission for the Environment (hereafter, CONAMA, for its name in Spanish) and from the Ministry of Health, the Ministry of Mining, and the Ministry of Finance; researchers from universities; private consultants; and mining company representatives. All of these actors were active participants in developing arsenic regulations, contributing in the form of research results, being members of the advisory committee, and developing official resolutions and recommendations presented to the political authority.

The case study involved mixed methods of inquiry, including literature and archive review and interviews. The initial chronological outline of the regulatory process was reviewed and enriched, resulting in a detailed description of the process. Primary data collection took place between November 2016 and August 2017. Selected documents and notes from archive examination and other sources were digitised. All data were entered into NVivo qualitative data analysis software and coded according to the guiding questions provided for characterizing each of the three layers of analysis proposed by van Kerkhoff and Pilbeam (2017). Data analysis using the knowledge governance framework distinctions resulted in an interpretation of the science-policy relationship.

The literature reviewed included scientific publications and regulatory documents related to the case study. The new regulatory framework required that CONAMA maintain an archive documenting the discussion process for new regulations, and the resulting archive consists of three volumes covering the period from 1996 until 1999, when the regulation was instated. Reports covering 1995 through 1997, and subsequent publications up until 2008 produced by the FONDEF 2-24 project were also reviewed.

We conducted thirteen in-depth interviews with actors purposively selected from relevant institutions: CONAMA (five interviews), FONDEF 2-24 project (three interviews: the director and deputy director, each with engineering background, and the health module leader, with public health background), the Ministry of Health (one interview), the Ministry of Mining (two interviews), the mining association (one interview), a mining company (one interview). Interviews were conducted in person, in Spanish, and lasted for approximately one hour each; all interviewees were informed of the research objectives and consented to the use of interview material for academic purposes. Following an open-ended question regarding career background and participants' working trajectory in environmental issues, interviewers asked questions focused on the details of each subject's participation in the development of arsenic regulation. Interviews were recorded –except when the interviewee preferred otherwise- and transcribed.

4. Case study: Regulation of airborne arsenic in Chile

Chile faces significant arsenic pollution (Ravenscroft et al., 2009). Arsenic derives both from natural volcanic activity in the Andes and from anthropogenic sources, including copper mining and smelting activities. Mining is fundamental to the Chilean economy and in 2010 copper production represented nearly 20% of GDP and more than 50% of exports (Comision Chilena del Cobre (COCHILCO), 2012). Arsenic pollution is concentrated in the north of the country and affects approximately 1.8 million people, 12% of the Chilean population (Sancha and O'Ryan, 2008).

Arsenic pollutes water, air and soil, and human exposure is connected to cancer. Scientific evidence of the health impacts of arsenic on the population living in the north of the country has long existed (Bruning, 1968; Borgoño and Greiber, 1971; Puga et al., 1973; Borgoño et al., 1977; Sancha et al., 1992; Ferreccio et al., 1996; Rivara et al., 1997). Abatement of arsenic in drinking water began in the 1970s and included the establishment of ambient standards based on WHO recommendations, and the construction of water treatment plants to remove arsenic (Sancha and O'Ryan, 2008).

In the 1990s, the need for airborne arsenic regulation gained attention and urgency. First of all, environmental management was declared a priority of the new democratic government, representing a point of contrast with the dictatorship's policies (O'Ryan and Lagos, 2005). As confirmed by our interviewees, the Ministry of Mining and the mining association recognized that environmental management in the Chilean industry was lagging far behind international competitors. The Ministry of Health raised public health concerns regarding arsenic's carcinogenic properties and argued for its regulation. At the same time, economic threats to Chilean copper exports based on a lack of environmental considerations applied pressure to the mining sector. During the 1980s, U.S. mining companies requested that the International Trade Commission accuse Chile of environmental dumping of copper. Although the petition did not go through, the latent risk of a formal accusation existed (O'Ryan and Ulloa, 2001; O'Ryan and Sancha, 2000). The new democratic government assigned priority to strengthening international relations by subscribing to trade agreements, in particular with the U.S. and Canada. This imposed improvements on Chile's environmental stewardship, especially in terms of pollutants affecting human health (Campusano Droguett, 2000).

The uniquely high levels of arsenic present in Chile and the significant economic consequences of mitigating copper mining emissions made transferring standards from other countries unfeasible from an economic perspective. The mining association claimed that copying standards from WHO or EPA would imply closing down most copper facilities. WHO's standards, proposed by the Ministry of Health, did not consider specific country conditions. The EPA has a process to define the ambient standard based on acceptable risks that could be adapted to local conditions. Using the EPA approach required scientific evidence on the local baseline conditions.

The history of arsenic emission regulation can be divided in two stages: before and after the enforcement of Chile's first Law for the Environment in 1994. Law 19.300 created the national environmental authority (CONAMA) and redefined Ministerial responsibilities for environmental issues. CONAMA became the coordinating entity for the preparation of environmental standards and regulations, and the primary actor responsible for the enactment of related legal procedures.

Prior to the enactment of the Law 19.300, the central government convened an advisory committee for regulating copper smelters' emissions. The advisory committee included representatives from the

Ministries of Health, Mining, Treasury and Agriculture. Members reached agreement on an ambient standard for anhydride sulphuric and particulate matter emissions. One of the convincing arguments in the discussion was the fact that using recovered anhydride sulphuric matter covered the investments costs in abatement technology. When it came to arsenic emissions, committee member's positions divided. Representatives from the Mining and Treasury Ministries argued that regulating would imply closing down a majority of smelters. The Ministry of Health called for attention to the health damaging effects of arsenic based on the WHO recommendation for an ambient standard and the results of a study they had commissioned in the late 1980s (Rivara et al., 1997, based on previous reports to the Ministry of Health not available in public archives). The resulting decree established an ambient standard for anhydride sulphuric and particulate matter and an explicit commitment to obtain more evidence on arsenic, in effect postponing arsenic regulation (DS185 by the Ministry of Mining, issued in 1992). DS185 contributed to fostering a plan for the decontamination of smelters across the country, and the advisory committee continued to build the body of evidence required to propose an ambient arsenic standard to the Ministry of Health.

On April 18th 1994, the Ministry of Health issued a supreme decree establishing maximum concentration of arsenic in the air (DS477). The mining sector considered the established levels impossible to achieve. However, on June 14th 1994, the Ministry of Health *retracted* the norm at the request of government authorities (DS1364), an exceptional action. The Secretary of the Presidency reported that airborne arsenic would be regulated under the institutional framework provided by Law 19.300, enacted 9th of March 1994.

Law 19.300 declares that regulations should not be simply imported or replicated but rather based on evidence of local conditions (Law 19.300 and Procedure DS93 SEGPRES, 1995). CONAMA was officially recognized by the Law as a new mediating actor, assuming responsibility for environmental regulation, a role that had previously been managed primarily by the Ministry of Health via the application of the Sanitary Code.

Anticipating the enactment of the Law, at the end of 1993, the government, through CONAMA, invited experts from the University of Chile to present a research proposal to inform arsenic regulatory policy. The request was to generate background information on arsenic baseline levels, health effects, control options, potential emissions reductions and costs; and propose criteria for regulation. Since the Law was not yet enacted, there was no provision of funds for such a study. The Ministry of Health hired consultants with a modest budget and a limited scope to study the health effects alone.

CONAMA suggested that researchers apply to the FONDEF public grant program. The FONDEF program was founded in 1991 to foster scientific and technological development to promote economic competitiveness and improved quality of life for Chilean citizens. It was run by the National Agency for Science and Technology (CONICYT), which depended on the Ministry of Education. It was thus independent of any of the parts in conflict. The funding application was supported by the Ministry of Mining. This proposal would become the FONDEF 2-24 project, entitled "Protection of the competitiveness of Chile's mining products: antecedents and criteria for environmental regulation of arsenic" which was undertaken between 1994 and 1996.

During 1997 and with the results of the FONDEF 2-24 project in hand, CONAMA coordinated an advisory committee for the preparation of guidelines for airborne arsenic regulation. The regulatory instrument was enacted in 1999 (DS165, SEGPRES).

The arsenic regulatory process stands out from usual standard setting in Chile for its incorporation of significant research efforts, of which the FONDEF 2-24 project was the most significant. The project represented a decisive intervention to integrate science within the regulatory process. Research results, together with additional scientific and technical reports, were used to establish both the specific regulatory approach – differentiated emission standards based on risks instead of a unique ambient concentration standard – and the level of the standards for regulating arsenic air emissions in 1999 (DS165 SEGPRES). Interviewees for this investigation agree that the FONDEF 2-24 project represents a success story of collaboration between researchers and policy makers for the application of scientific knowledge to policy making.

In order to better understand this success in informing policy-making within the framework of knowledge governance, Sections 4.1–4.3 apply the questions proposed by van Kerkhoff and Pilbeam (2017:33).

4.1. The civic epistemology of regulation in the 1990s

Civic epistemology is characterized by participatory styles, by the actors with public endorsement to take part in knowledge production, and by practices to generate trust and accountability. There is also consideration of expertise formation, and issues of transparency and objectivity (van Kerkhoff and Pilbeam, 2017; Jasanoff, 2005). The Chilean case study occurred during a period of political transition and transformation relating to each of these factors, which need examination to better understand the success of the intervention.

Societal beliefs are interwoven with concepts of authority, power struggles, and mindsets (Jasanoff, 2012). Given the complexity of depicting civic epistemology in the dynamics of the transition period, we provide a general overview of the main factors involved.

The 1990s in Chile were characterized by deep social and political changes. Chile lived under a dictatorship from 1973 to 1989. The fledgling democracy was bounded by "the extent of what is possible". That phrase – spoken by President Aylwin, the first democratically-elected President of the transition period – became a reference to understand the double challenge of recovering democracy, while maintaining peace with the military's interests (Garretón, 2002). It was in this context that the policy field of environmental management emerged (O'Ryan and Ibarra, 2017).

The uncertainty of a transition to democracy within a context of ongoing military power often shaped decision-making, and created a so-called "democracy of consensus". Chilean politicians' primary concerns revolved around rebuilding the State and defining the State's role in achieving social cohesion, maintaining a fragile political balance, and supporting economic growth while defending the recently recovered democracy (Silva, 2002). Furthermore, the dictatorship had severely intervened in the universities, so scholars were also reshaping their place in society, and rebuilding the foundations of expertise. Thus, implications of civic epistemology in generating public knowledge, its accountability, and effectiveness, were fuzzy, since crucial actors, such as the State and experts, were in the middle of redefining their roles and relationship with society.

Economic growth during the dictatorship had been self-labeled the "Chilean miracle" (Gárate, 2012). Copper production was fundamental to Chile's economy and therefore a key element in the political equation during the transition to democracy. The new State could not risk jeopardizing copper production, a point emphasized by the Ministry of Mining during the development of arsenic regulation.

The new government wanted to modernize the State but had almost no experience in shaping government structure (Waissbluth, 2006) or in integrating expert opinion within public policy development. After 17 years of dictatorship, many 20th century institutions had imploded. Chilean society was seeking to give meaning to being a social actor; then, understanding the particular role of scientists was not top of mind, despite the importance this may have had (Miller and Neff, 2013).

The goal of protecting democracy was paramount. As politicians learned to develop public policies (Boeninger, 2007) and organize priorities, a long-lasting discourse of underdevelopment in Latin America placed environmental policy as subordinate to economic growth (Carruthers, 2001). Additionally, developing economies and

societies, in general and including Chile, understood environmental issues primarily as they related to public health, rather than as efforts to protect the environment. Nevertheless, the government was committed to improving environmental stewardship, and used the constitutional right to a clean environment (Chilean Constitution, 1980) as a stepping stone.

The perception of the international community about Chilean environmental management was particularly sensitive for Chileans. The country had a long history of relating itself with the developed world and sought economic and cultural models in Europe and, afterwards, in the United States (Silva, 2008). Even if the dictatorship had a close relationship with anticommunist countries at first, during the 1980s Chile experienced a near international abandonment (Morley and McGillion, 2015). After the dictatorship, Chileans were not only trying to rebuild the State and to bolster social cohesion, but were also finding their place in the international community. Credible environmental policy was important to this process. Thus, we can understand why the U.S., and specifically the EPA, greatly influenced Chilean arsenic regulation. Producing public knowledge included participation of international actors, who had a role in securing objectivity.

Within a political culture of authoritarianism (Brunner, 1981), decision-making and public policies had traditionally been defined within a hierarchical structure, which was only accentuated during dictatorship. Decision-making processes included only the State and selected experts, with no participation from civil society in these debates. In the early years of the democratic transition, environmental responsibilities and institutions were redesigned, making it difficult to determine responsibility for the emergent policy field of environmental management (Miller, 2007). Traditional understanding indicated that knowledge was not produced in the post-colonial area of the world, but rather imported, reshaped and appropriated (Raj, 2017). It remained to be seen how an emerging group of experts could produce scientific knowledge to support regulatory decisions on arsenic regulation. In addition, this case could prove that environmental concerns were much better addressed by democratic regimes than by dictatorships, as stated shortly after the arsenic discussion (Silva, 1996a). The new government would have to show it was feasible to protect the environment and the economy (Silva, 1996b), an avoid open conflicts, because they could be perceived as weaknesses of the new democratic state, as happened in the following decade (Barandiaran, 2015).

Finally, governance itself represents a key challenge in Latin America, a region often described as chaotic, untrustworthy, and corrupt. Within this context, Chile has considered itself an exceptional country (Silva, 2017), with stable institutions, a relatively quick process of state building in the early 19th century, and widespread societal trust in the rule of law (Silva, 2008). Participating actors' sense of pride in the successful development of arsenic regulation within a complex political scenario is partially explained by this sense of exceptionalism. Regulatory development demonstrated that institutions were functioning within the new democratic Chile, even if laws were treated as separate from politics (Barandiaran, 2016).

In this way, multiple contextual factors converged in the development of arsenic regulation, including Chilean historical identity and the perception of Chilean environmental management by the international community.

4.2. Knowledge system

In this section we explore the institutional arrangements shaping the relations between science and decision-making. We first introduce the rules applying to the process, and next investigate the dimensions of credibility, salience and legitimacy as suggested by van Kerkhoff and Pilbeam (2017) and Cash et al. (2003).

The boundary between science and environmental policy making changed in the 1990s with Law 19.300, which mandated that environmental regulations be based on scientific evidence regarding local conditions. Both health and economic factors had to be considered. The Law itself was an adaptation of a European one; there are no registers of discussions on the production of local science.

In the middle of the controversy between the Ministry of Health and the Ministry of Mining, and while Law 19.300 was being discussed in Parliament, the central government saw the full application of the new Law as a path for reaching consensus and ensuring that environmental policy would not be an obstacle for economic development.

There was also a knowledge need; not copying the international standards implied presenting evidence and making an argument for a local norm, which would be scrutinized by international organizations, especially at the request of copper competitors. Additionally, the mining industry needed time to examine options, make the necessary investments and implement technological change. To be successful, the regulatory process had to achieve international acceptance and internal consensus.

4.2.1. Credibility

Concerting a broad range of expertise was important for the credibility of the regulatory process. As the conductor of the process, CONAMA decided on the inclusion of a diversity of expertise.

Once FONDEF 2-24 concluded, CONAMA coordinated an advisory committee and convened a network of actors to develop the regulatory instrument. CONAMA identified interested and informed stakeholders from the Ministry of Health, the Ministry of Mining, the mining companies, and experts (primarily but not exclusively participants of the FONDEF 2-24 project). The public archive shows that participation in committees, discussions and any formal consultation was restricted to representatives of these institutions and actor groups. The issue was not covered by the media, for example, there is no register of a public debate in local newspapers.

Authoritative knowledge was linked to international actors, who were references for regulation. The Ministry of Health adapted WHO standards to the Chilean context and maintained a strong relationship with the WHO, which supported research and training. In the case of copper production, participants in discussion expressed interest in achieving standards approved by organizations such as the EPA, which was the accepted technical body for U.S. mining companies and the trade agreements negotiations.

Science-based knowledge also played a formal role in making the process accountable. Diverse scientific expertise was considered during the regulation's development. The FONDEF 2-24 project included several research modules and an interdisciplinary team covering health related impacts, technological issues, pollutant dispersion and economic impacts.

4.2.2. Salience

The invitation to present a project and the first approach to defining the objectives of the research came from the policy makers themselves. In applying for competitive funding, the project leaders argued that policy needs motivated the initiative. The FONDEF 2-24 project had a steering committee with representatives from the different parts involved and recognized by CONAMA as stakeholders to the process, including representatives of the Ministries of Health and Mining, CONAMA, and mining companies. The committee followed the project's development and represented the primary mechanism for communicating the knowledge needs of decision-makers to researchers.

Each actor present during discussion played a role in ensuring that the proposed regulation responded to their needs and concerns. The Ministry of Health sought to prevent environmental conditions that could endanger human health. The Ministry of Mining defended the interests of copper production for economic growth and increasing international trade and foreign investment. Mining companies were included in the discussion given the need for industry investment in new practices in response to the regulation, and the importance of assessing technological and economic options and their feasibility. The National

Copper Corporation, CODELCO, was the main copper producer and, as a public company, contributed significantly to the government treasury and to these discussions. The participation of multiple actors representing diverse interests was regarded as adding credibility and salience to the process.

4.2.3. Legitimacy

Once the project ended, CONAMA led the regulatory process and acted as discussion mediator, gathering scientific advice for finding feasible solutions. The views from the Ministry of Health and the mining sector differed in terms of desired outcomes. The Ministry of Health's position was strong and unambiguous: arsenic should be regulated under an ambient standard that protected human health equally across the country. In contrast, the Ministry of Mining resisted regulation based on an ambient standard arguing that enormous investment would be required to reach the proposed ambient levels and that available information did not allow for an adequate evaluation of costs and technological feasibility; in case of regulation, the Ministry of Mining favoured an emissions standard. As mediator, CONAMA pushed to advance regulation in the mining industry without creating an economic disaster for the copper sector.

According to the minutes in the archive, compromise was reached during the second committee meeting:

The FONDEF 2-24 project recommends, and CONAMA agrees, to begin solving the problem of arsenic air pollution with the establishment of an emissions standard and, within the following one to two years, with the establishment of an ambient standard, which should consider new research in measuring naturally-occurring concentrations. (Arsenic Norm file, page 000039, authors' translation)

In summary, this section presented the main elements shaping the boundary between science and policy-making, at a time of new institutional arrangements. In terms of credibility, knowledge accepted by policy-makers was represented in the advisory committee coordinated by CONAMA. Participation, restricted to these knowledgeable actors, supported the credibility of the regulatory process. To the people involved, this was a process where everyone with an interest at stake had a place in the discussion. The regulatory process was accountable to national and international interested parts.

Regarding salience, science produced during the process responded to a policy-maker demand (CONAMA) and the steering committee, which supervised research development. There was also the quality assurance system used by FONDEF to select and assess projects, and FONDEF 2-24 conformed to this system.

In terms of legitimacy, there were different concepts of public good, and science had a role in mediating amongst them. Science results offered a solution by calculating the effects of different pollution levels on health and finding the limit beyond which further pollution reductions did not result in significant health benefits. Reaching consensus and equilibrium between economic development and other values was desirable and legitimate in the post-dictatorship context.

4.3. Intervention: FONDEF 2-24 project

This section pays special attention to science-policy communication practices, accountability recognition, negotiation and mediation, and boundary roles, all of which represent the third layer, intervention. Using the approach of van Kerkhoff and Pilbeam (2017), we can see how the FONDEF 2-24 project managed to be instrumental in reshaping the science-policy relationship in Chile. The FONDEF 2-24 project both contributed to the construction of new institutions for environmental management and demonstrated the functionality of the new order.

The project budget was US 700,000, a large-scale research project by Chilean standards of the time. Neither CONAMA nor any of the Ministries involved would have funded this study on its own, and none would have taken responsibility for the project's scientific supervision to achieve credibility with the other Ministries. A research project with industry impact fitted the purposes of the FONDEF program, particularly in a sector of economic priority.

This specific intervention gave significant incentives to academics. At this time, universities had limited research funding after the reforms of 1981 (DFL N°1 and DFL N°4) and 1990 (Law 19.962, known as LOCE) and the project allowed complementing salaries. The concept of "research universities" was new to the Chilean education system and was used to differentiate between institutions (Bernasconi, 2007). Indexed scientific publications became increasingly important for academic assessment and career advancement, and the FONDEF 2-24 project supported the development of numerous research articles (e.g. Ferreccio et al., 1998; O'Ryan and Sancha, 2000; O'Ryan and Lagos, 2005; Sancha and O'Ryan, 2004, 2008; Ferreccio and Sancha, 2006).

The research team was multidisciplinary and included academics from the civil engineering, mining engineering, chemical engineering, industrial engineering, and health departments of the University of Chile. FONDEF 2-24 was organized in a modular fashion, with each module centred on a different expertise. In response to the initial policy demand and to the steering committee advice, the project generated data on arsenic baseline levels in Chile, population exposure, health impacts, technological alternatives for emissions abatement at smelter sites, technological options for arsenic removal from drinking water, risk-cost evaluations of regulatory options, and economic analysis for technological change (FONDEF2–24, 1997).

4.3.1. Communication strategies and translation

The steering committee discussed research design and intermediate results. It was recognized by researchers interviewed as advocating for attention to policy needs throughout project development. FONDEF 2-24 used data provided by committee members and invited all parties to research seminars to promote an on-going science-policy dialogue between sectors. Interviewees agreed on a sense of having been part of a collective learning process.

The technical people at CONAMA, the advisory committee, the project steering committee and the project researchers were amongst the most knowledgeable people on the subjects in Chile at the time. International expertise did not cover the specificities of local conditions.

4.3.2. Accountability

The research team understood the need to produce results that were trusted and considered valid by project stakeholders (the Ministries of Health and Mining, the mining companies and CONAMA). The scrutiny of relevant international institutions represented another important consideration; they needed, in researchers' words, to "gain the EPA´s blessing". This recognition by peers in the international community would not only be an indicator of the project's scientific success but also represented a contribution to the country's reputation within the international community.

Project actors balanced the influence of their own peers within the national scientific community, different public offices in Chile, and the international community. The combination of the project's direct accountability to a non-interested part (FONDEF) and consistent incorporation of relevant stakeholders in discussion gave legitimacy to the proposed regulatory standards. Following the presentation of project results, the project director attended all of the regulatory advisory committee meetings to develop the final regulatory legislation.

During interviews, researchers also highlighted the project´s "financial independence," noting they were accountable to FONDEF authorities, who approved final reports and were not an interested part in the arsenic regulation.

4.3.3. Boundaries, negotiation and mediation

Members of the steering committee and the regulatory advisory committee acted as boundary workers, communicating and translating the results of technical meetings and reporting back to the policy level

(to Ministers, for example).

This committee additionally presented a space to discuss and negotiate research decisions throughout project development. During interviews, researchers indicated that they were able to maintain independence and autonomy in final decision-making because of the project's financial independence.

One key tension related to the Ministry of Health's promotion of an ambient standard of 0.05 g/m^3, while the Ministry of Mining argued for an emissions standard. FONDEF 2-24 project results indicated that significant health benefits could be achieved by limiting values of ambient arsenic to approximately 0.15 g/m^3. Additional reductions toward the 0.05 g/m^3 limit did not result in significant additional avoided deaths and did imply steep increases in mitigation costs. The project also determined that the cost of achieving different standards as well as the health impacts varied widely among smelters. In response to this heterogeneity, the project estimated technical feasibility, risk, costs and benefits for different scenarios, and proposed a specific emissions standard for each of the seven smelters in the country, rather than a uniform ambient standard (FONDEF2–24, 1997). Though this was an important deviation from the Health Ministry's proposal, it incorporated both costs and health concerns.

In addition to the recommendations regarding airborne arsenic pollution, the FONDEF 2-24 project concluded that the effects on human health of arsenic pollution from water contamination were greater than those from airborne exposure (FONDEF2–24, 1997), i.e. that arsenic regulation should consider the different exposure paths. This was important because despite steady improvements since the 1970s, the local standard for arsenic in drinking water remained above WHO recommendations, and some rural communities lacked access to treated water. The study, therefore, recommended that efforts concentrate on improving drinking water quality.

The final regulatory standard (DS165, SEGPRES, 1999) – that closely followed the FONDEF 2-24 recommendation – represented an emissions standard, which specified maximum limits of arsenic emissions in tons per year. These limits are associated with location (by administrative region) and emission source production capacity; the proximity of human settlements is also considered in these calculations. In most regions, the maximum limit distinguished an initial value as of year 2000 and a lower limit from 2003 onwards.

In summary, The FONDEF 2-24 project played a role in the subsequent development of new environmental management institutions in Chile. It demonstrated the functionality of the new order, particularly of applying science to policy decisions through a transparent procedure. To that extent, it was a successful knowledge-to-action experience.

5. Discussion on applying knowledge governance to a Latin American case study

The knowledge governance approach allows a better understanding of the science-policy interface, moving beyond an intervention-based focus. It situates the FONDEF 2-24 project within knowledge governance in transition, i.e., involving significant changes at the three layers of analysis, i.e., civic epistemology, knowledge systems and interventions. In this section we weave together the main contributions of this case study from our multi-layered perspective.

The Global Development Network (GDNet) study, mentioned in Section 2, that focused on the characteristics of the intervention, emphasized the need for a specific and early mandate by policy makers for scientific evidence and the importance of communication efforts by researchers towards policymakers, beneficiaries and funders; research quality; and the prestige and neutrality of researchers. Although these factors are important for bridging the science-policy gap and were present in the FONDEF 2-24 project, such an intervention-focused study fell short in explaining the relevance of institutional and historical circumstances for the success of this intervention.

5.1. An explanation for success: Alignment

The success of project FONDEF 2-24 can be better explained through the lens of knowledge governance, focusing on the complex interactions of civic epistemology, knowledge systems, and interventions. Alignment emerges as significant in determining the project's success in actively informing policy making, and as the opportunity to regulate an issue of known public health concern, which had been neglected for at least a decade.

The FONDEF 2-24 project was well aligned with the new arrangements governing science-policy relationships, and with the civic epistemology of the 1990s, i.e., there was coherence amongst the three layers of analysis in terms of the direction they were taking over this time of transition. The FONDEF 2-24 project was a test of the emerging space for science in policy development, and it played a mediating role among different actors with diverse interests in the regulatory process.

The idea of achieving consensus permeated the three layers of analysis and may help explain the ways in which contradictions in public policy were resolved. Differences among stakeholders, though significant, were maintained within the limits of the project steering committee, the regulatory advisory committee and the State bureaucracy. This might be an expression of making policy "to the extent of what is possible".

The three layers of analysis also aligned in terms of the need for knowledge regarding the economic impacts of environmental policy decisions and internationally accountable. The FONDEF 2-24 project incorporated modules focused on both health and economic analysis. It was accountable to international opinion, and contributed to building trust in and recognition of Chilean institutions. Within the knowledge system layer, new regulations explicitly included sound science and transparent processes, like those in the developed world, and the FONDEF 2-24 intervention produced knowledge accepted by international organizations, and resulted in publishable research results. Finally, trust in public reason was deeply linked to validation of international referents.

There was also alignment with other spheres governing knowledge production, in particular the academic one. Some researchers were personally committed to regulating arsenic, however the FONDEF 2-24 project also presented multiple benefits for the researchers involved. These benefits ranged from the associated funding and project horizon, a luxury compared to normal research budgets, to opportunities to develop a research agenda related to arsenic regulation and comply with recently established publication requirements for strengthening academic careers, thus allowing for local development and deepening of scientific expertise.

Although, there was a diversity of interests among decision-makers, there was an alignment towards the common goal of completing a regulatory process, accountable to the quality assurance requests of international bodies. There was also the shared understanding that environmental regulation should not generate political tensions, which implied reaching consensus. In this context, the research project provided a space for mediation and time for accommodating to a new regulatory framework.

5.2. Impact and timeframes for researchers and policy-makers

The approach used requires defining a timeframe for the analysis that is wider than the duration of the specific intervention and even the extent of the surrounding policy process. The process of regulating airborne arsenic in Chile took almost ten years and spanned two government administrations. FONDEF 2-24 project ran for two years, and researchers worked on final reports and attended meetings for an additional year.

Researchers invested time and effort, which was not necessarily valued in their academic environment at the time, at least not until they had published results. However, knowledge results and capacity

building had an important impact in the researchers' careers and teaching over the following decade, as indicated by interviewees and demonstrated in the numerous publications following from the intervention, the continuity of working relationships among participating researchers and the on-going research on arsenic health impacts to date.

Researchers guided multiple graduate and undergraduate thesis related to the project. The project experience informed their teaching and approaches to policy advising. These researchers' teaching, publications and public opinions may in turn have influenced the dynamics of the formal and informal rules underlying science-policy relations (i.e., the civic epistemology layer).

For regulators, this process began prior to the FONDEF 2-24 and concluded with regulatory implementation and the institutionalization of a procedure for incorporating expert knowledge within policy making. Civil servants, who were technical experts, lent continuity to the process and acted as boundary workers between expertise and the political spheres of decision making. "Political commitment" has been named a factor of success in the arsenic case (Mardones Fuentes, 2005). However we contend that the previously mentioned factors relating to knowledge governance and the strategic relevance of this regulatory process allow for better understanding of the process continuity over time and the inclusion of the project's research in the policy process.

5.3. Influence in shaping the emergent policy field of environmental management

The arsenic regulatory process, with the contribution of project FONDEF 2-24, introduced ideas of trade-off analysis, as a way to manage irreconcilable discussions, and the acceptance of "reasonable risks" to define standards (O'Ryan and Díaz, 2000). These concepts contributed to the opening of discussions regarding new forms of regulation in Chile, which over time transformed public knowledge production. The application of science to inform regulations, particularly trade-offs and economic impacts, has become mainstream.

Revisions to the norm, mandated by Law 19.300, are an example of this new order. The arsenic standard (DS165, issued in 1999) has been reviewed twice, and in both cases policy has been informed by expert's studies commissioned by CONAMA. The first revision (DS75, SEGPRES, 2008) refers to improvements to applied methodologies. The second revision (DS28, Ministry of the Environment, 2013) modified emission standards and is grounded on the principle of efficiency, reducing pollution levels at the lowest possible social cost. It considered technical, economic and social criteria, and specifically a complete diagnosis for each smelter to determine the dispersion of pollutants to the atmosphere, toxicity and emission's effects, the efficiency and efficacy of current regulation, the availability of control technologies, and trends in international regulatory practices. This second revision quotes a 2005 recommendation of the Organization for Economic Cooperation and Development (OECD) regarding further reductions to smelter emissions, particularly arsenic - once again highlighting a concern with international accountability.

Almost twenty years after the first regulation of airborne arsenic, the standard has not changed significantly. The Ministry of Health lost regulatory power, and an approach that incorporates environmental, social and economic costs, as well as health has been established. Environmental standards are now the responsibility of the Ministry of the Environment (created in 2010 under Law 20.417 to replace CONAMA). In fact, for the first time in Chile's regulatory history, the most recent modification to the arsenic emissions standard (DS28, Ministry of the Environment, 2013) was signed by the President, the Minister of Environment and the Minister of Mining, but not by the Minister of Health.

6. Conclusion

The 1990s brought deep social, economic and cultural changes in Chile and most of Latin America. The policy field of environmental management emerged giving a formal role to science, and science also had an impact on shaping the field of environmental management. The application of a knowledge governance approach to examine the case of airborne arsenic regulation in Chile in the 1990s allows a better understanding of this complex relationship between science and policy making by defining as dimensions for analysis the interactions between the intervention, the prevailing knowledge system, and observed civic epistemology.

The success of the FONDEF 2-24 project in actively informing the regulatory process is related to the alignment among these three layers of analysis. The project contributed to the construction of new institutions for environmental management and demonstration of the functionality of the new order, which strengthened democracy without threatening the economy. The project also aligned with concerns for international accountability. The prevalence of a politics of consensus in the aftermath of the dictatorship permeated the three layers of analysis.

Knowledge produced by the FONDEF 2-24 project played an important mediating role between contrary positions during the regulatory process. There were clear tensions between actors seeking different outcomes, and scientific evidence, which provided new perspectives based on trade-off analysis and the idea of acceptable risk, served to facilitate compromise. The intervention provided time for actors to accommodate in the emergence of the policy field of environmental management, which was well established by the end of the 1990s.

Policy processes and regulations require understanding beyond scientific and expert knowledge, including a consideration of politics and political culture, which can be examined through the lens of knowledge governance. Our case study highlights the importance of considering the three layers of knowledge governance analysis and their relationships when designing science-based policy interventions and a timeframe tuned to the policy process and the intervention impacts. In our case, alignment led to a successful experience of science informing policy. We do not imply alignment is a recipe for success, but it should be considered when designing and analysing policy interventions.

We see value in documenting local environmental history and scrutinizing policy development under the conceptual framework of knowledge governance. It can help reflect on the science - policy interface in Chile and other countries, and shed light on conflict and other factors hidden in the traditional focus on science or politics.

Further research could be undertaken on the balance of power in the institutional arrangements formed in the 1990s and the evolution of knowledge systems and civic epistemology. In this study, we advanced in showing the dynamic relation between the three layers of analysis. The time of emergence of the policy field of environmental management offered the opportunity for establishing new relations between science and policy-making, and, also, for installing new ideas influencing institutional order and substantive authority in the emergence of the field. Science did contribute to shape this new order.

Despite historical differences between the 1990s and the 2010s, knowledge governance offers a valuable approach for reflecting on the deeper and wider layers of policy decisions and the ways in which science can better inform policy-making. The current decade presents new challenges in Chile and elsewhere, including questions surrounding the growing role of citizen participation, environmental rights, and the emergence of climate change adaptation as a policy field. The emergence of a policy field presents an opportunity for science to participation. Knowledge governance can help researchers situate science within the policy process, considering what is needed, possible and more likely in the current circumstances.

Declarations of interest

None.

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