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ANALYSIS

The bandwidth problem in telecoupled systems governance: Certifying sustainable winemaking in Australia and Chile

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ABSTRACT

Telecoupled systems connect consumption and other choices in one part of the world with land-use and land-cover change in another. While such connections are increasingly well documented, research on governing telecoupled systems is in its infancy. Drawing on recent discussions in sociology, we argue that models for governing telecoupled systems must consider two types of information flows. Low-bandwidth flows allow for limited information transfer but can take place over greater distances. High-bandwidth flows, by contrast, allow for more complex knowledge transfer but tend to be geographically localized due to the costs of maintaining robust connections. Using a mixed-methods case study of national sustainability certification in the wine sector in Australia and Chile, we argue that Chile's counterintuitive success in diffusing its national sustainability certification relates to its geography, which facilitated high-bandwidth connections. We conclude that telecoupling governance measures, such as jurisdictional commodity certification, need to consider the unique requirements and costs of high-bandwidth connections in allocating institutional investments.

1. Introduction

Global trade drives forest loss and other land-use change, affecting biodiversity and climate (Krausmann and Langthaler, 2019; Pendrill et al., 2019). The recently developed telecoupling framework focuses on the environmental consequences of globalization and analyzes the world as a network of coupled human-natural systems connected by energy, material, biological, and information flows (Liu et al., 2013). How better to govern telecoupled systems is an open and pressing question (Galaz et al., 2012; Hull and Liu, 2018; Kaspar et al., 2019; Liu et al., 2013; Munroe et al., 2018; Oberlack et al., 2018), with relevant theoretical resources and empirical research often falling between disciplines like political science, sociology, geography, economics, and ecology (Challies et al., 2019).

There is consensus in the telecoupling literature that robust governance requires robust information (Challies et al., 2019; Hull and Liu, 2018; Kaspar et al., 2019). This article further develops telecoupling theory's core concept of information flows through a mixed-methods analysis of sustainability certification in the wine sector in Chile and Australia. We agree with existing literature that telecoupled agents need reliable communication, and that information flows are necessary for technological or practical innovations to diffuse. However, we argue that practice diffusion requires more robust information flows than communication. Borrowing terminology from sociology, we suggest that low-bandwidth information flows, where weak connections between actors allow for limited information exchange, may be sufficient for communication, while diffusion requires high-bandwidth flows, characterized by dense and frequent exchange (Aral and van Alstyne, 2011).

While it may be possible to sustain low-bandwidth flows across long distances, high-bandwidth flows tend to be more resource-intensive and, therefore, geographically constrained. Effective telecoupled systems governance requires supporting high-bandwidth connections when necessary while relying on low-bandwidth links where possible. While the telecoupling literature emphasizes transnational links, telecoupling governance should be agnostic as to whether the connections in question are transnational, domestic, or, as will most often be the case, both. To understand and respond to distant teleconnections, in other words, it may often be necessary to consider local ones.

We elaborate these ideas using a mixed-methods case study of sustainability certification in the Australian and Chilean wine sectors. Discussions of governance for telecoupled systems often list

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environmental certification as a possible way to facilitate information flows promoting more sustainable management (Carrasco et al., 2017; Challies et al., 2019; da Silva et al., 2019). To our knowledge, however, no study considers environmental certification from a telecoupling perspective. To be clear, our objective in this case is not so much to see what telecoupling can tell us about environmental certification as what we can learn from environmental certification about crafting information flows to govern telecoupled systems.

The Australian and Chilean wine industries are excellent comparative cases for exploring environmental certification, featuring similar production levels, industry concentration, and export markets. Amid concerns about wine's environmental impacts, both countries developed national sustainability certification initiatives, with divergent results. Based on our comparison of the two cases, we argue that production geography - and its implications for the potential to build high-bandwidth connections promoting diffusion - is a critical and underappreciated factor affecting certification uptake.

Our research contributes to the telecoupling literature in a few ways. First, drawing on the bandwidth concept, we provide a simple way to distinguish information flows, supporting empirical and normative theorizing about telecoupling governance. Second, while researchers have suggested environmental certification can establish information flows between telecoupled places (Carrasco et al., 2017; Challies et al., 2019; da Silva et al., 2019), to our knowledge telecoupling studies have not yet investigated certification empirically. Third, our study highlights the costs involved in governance, which are often overlooked in the ecological economics literature (Jespersen and Gallemore, 2018).

2. Information flows and bandwidth in telecoupled systems

In a foundational article, Liu et al. (2013) define a telecoupled system as "an interrelated set of coupled human and natural systems that are connected through flows among them." Flows are movements of "material, energy, or information" facilitated by agents of "different types, e.g., individuals, households, organizations, [and] corporations." These flows connect "sending systems" from which material and energy flows originate to "receiving systems" in which they are consumed. Both sending and receiving systems are themselves complex coupled human-natural systems within which diverse agents interact.

Reviewing the first five years of telecoupling research, Kaspar et al. (2019) indicate understanding agents' embeddedness in institutions and flows should be a research priority, and others point out that governance tools effectively work by manipulating actors' embeddedness (Hull and Liu, 2018; Oberlack et al., 2018). Acknowledging that telecouplings often cross national boundaries, making sovereign policy solutions difficult, several commentaries consider non-state or hybrid governance as tools for managing telecoupled systems (Carrasco et al., 2017; Challies et al., 2019; da Silva et al., 2019; Hull and Liu, 2018; Larsen et al., 2018; Oberlack et al., 2018). Lacking sovereign enforcement power (Gallemore et al., 2018), such initiatives rely heavily on information flows, which are key contexts in which telecoupled actors are embedded (Gardner et al., 2019; Munroe et al., 2018). In this section, we introduce into the telecoupling literature a key theoretical distinction between low- and high-bandwidth information flows and consider how this distinction could affect telecoupled systems governance. Particularly, we argue, the bandwidth problem implies telecoupled systems governance requires considering not only distant informational teleconnections but also local ones.

2.1. Bandwidth and the geography of information flows

Many analyses of telecoupled governance consider how to leverage information flows to affect agents' choices. Connecting complex localized systems in often unknown ways, telecoupling causes "knowledge deficits" (Challies et al., 2019: 189–190) or "lost signals" (Hull and Liu, 2018) because agents are at best partially aware of their actions' consequences. Recent work in sociology divide information connections into high- and low-bandwidth types, both of which address different knowledge deficits. Aral and van Alstyne (2011, p. 119) define bandwidth as "the volume of communication over a given channel" through which information flows. Low-bandwidth flows are relatively low-cost channels characterized by limited information exchange. An example might be an email listserv or the presence of an ecolabel on product packaging. High-bandwidth flows are robust channels where information flows rapidly, with feedback (Aral and van Alstyne, 2011; Bruggeman, 2016; Sinan, 2016). Examples might include a college course or a multistakeholder forum that meets on a regular basis.

While any flow can expose actors to new information, complex or tacit knowledge transfer, essential to innovation or adoption of complicated knowledge or practices, often requires high-bandwidth flows (Bruggeman, 2016; Glückler, 2007; Hausmann and Neffke, 2019; Sinan, 2016). The social learning involved in adopting comprehensive certification practices is less likely to take place across distance. Complex and tacit knowledge, which underpins such learning, tends to diffuse through repeated, spatially delimited, contact. Trying to learn how to ride a bicycle or a pogo stick, for example, will often be easier taught in person than via a YouTube video.

This helps explain why complex sustainable practices often diffuse locally (Babutsidze and Chai, 2018; Tong et al., 2012). High-bandwidth flows are costly, particularly as distance and actor heterogeneity increases (Challies et al., 2019: 190–191). It takes time and resources to develop common languages or vocabularies, coordinated operating procedures, and trust to maintain high-bandwidth flows (Feiock et al., 2012; Gallemore et al., 2015; Gallemore and Jespersen, 2016; Hamilton et al., 2018; Hamilton and Lubell, 2018; Williamson, 1975). People often pay a price to spread complex practices. In-person martial arts lessons, for example, remain popular despite online videos. Because geographic proximity is associated with pre-existing similarities, lower communication costs, and greater interaction frequency, high-bandwidth flows tend to be local (Bathelt et al., 2004; Eriksson and Lengyel, 2019; Glückler, 2007; Juhász and Lengyel, 2018; Lengyel and Eriksson, 2017) or to follow established connections (Halleck-Vega et al., 2018).

These points suggest high-bandwidth information flows are more likely to be found within geographically delimited sending or receiving telecoupled systems. Information flows between distant systems, however, are more likely to be low bandwidth. These considerations should affect telecoupled systems governance. First, it may be necessary to make do with low-bandwidth connections to link sending and receiving systems, while it could be possible to foster high-bandwidth information flows within those systems, taken separately. Second, if the capacity to establish reliable low-bandwidth information flows depends on local high-bandwidth flows, then conditions within receiving and sending systems may constrain appropriate choices for using information flows as a governance tool.

2.2. Environmental certification in telecoupled systems governance

Work on telecoupling suggests environmental certification can be used to construct governance information flows (Carrasco et al., 2017; Challies et al., 2019; da Silva et al., 2019). Carrasco et al. (2017), for example, characterize certification - and the supply-chain transparency certification systems can promote - as a way to pressure agents to adopt responsible practices. Firms can use environmental certification to ameliorate lost signals between sending and receiving systems (Ibanez and Grolleau, 2008; Lozano et al., 2010; Blanco and Lozano, 2015; Schumacher, 2010). Certification acts as a low-bandwidth channel firms can use to send credible information about their sustainability performance (Gallemore and Jespersen, 2019; Gallemore et al., 2018).

Environmental certification, admittedly, has notable weaknesses as a low-bandwidth information flow (Bray and Neilson, 2017; DeFries, 2017). First, though consumers use ecolabels as a heuristic (Thøgersen

et al., 2012), they have heterogeneous preferences and willingness to pay (Delmas and Lessem, 2017; Moon et al., 2017; Schumacher, 2010). Second, certification seldom leads to significant price premiums or improved incomes, though it can have other benefits such as improved governance, social capital, learning, alternative livelihoods, and social services (Bray and Neilson, 2017; Carlson and Palmer, 2016; Degnet et al., 2018; DeFries, 2017; Glasbergen, 2018; Qiao et al., 2018; Sugiura et al., 2012; Uematsu and Mishra, 2012; van der Ven et al., 2018). Third, environmental outcomes from certification are mixed (DeFries, 2017; van der Ven et al., 2018), and there are well-founded doubts about schemes' credibility, enforcement, and compliance (Darnall et al., 2018; Greenpeace International, 2013; Opitz et al., 2016; Ruysschaert and Salles, 2014; van der Ven et al., 2018). Finally, certification has high costs, scale requirements, or technical skills that place it out of reach for smaller operations (Glasbergen, 2018; Hidayat et al., 2015; Hoang et al., 2019; Maguire-Rajpaul et al., 2018; Marschke and Wilkings, 2014; Sugiura et al., 2012).

Fundamentally, these problems rest on two informational challenges. First, certification must send reliable, low-bandwidth signals about sustainability between sending and receiving systems. Second, it must be possible for certification to diffuse across relevant markets. Governance arrangements within several transnational environmental certification initiatives, however, can push in the opposite direction. Power imbalances between actors from the global North and South, documented in several schemes (Higgins and Richards, 2019; Strambach and Surmeier, 2018), can incentivize constructing high-bandwidth, long-distance connections, such as detailed supply chain traceability, detracting Gardner et al., 2019; Glasbergen, 2018).

Previous literature on ecolabelling uptake has considered several levels of analysis, from individuals operation through national contexts to global value chains. While, as Prado and Woodside (2015) demonstrate, any individual operation's decision to become certified depends on complex antecedents, several possible drivers have emerged in the literature. Consistent with the argument that high-bandwidth flows will tend to be local, studies indicate proximity is a critical factor in adopting environmental certification (Albuquerque et al., 2007; Husted et al., 2016). DeBoer et al. (2017), for example, find spatial clustering in green tourism certification in Costa Rica. Cerqua (2017), similarly, find that Blue Flag sustainable tourism certification can increase domestic tourist arrivals, but only when the certification is used as a coordination mechanism. Geography is not the only factor relevant to uptake, however. The benefits to certified operations also matter. Here, the evidence is mixed (Blackman and Rivera, 2011). While some studies demonstrate direct economic benefits from certification (Fenger et al., 2017; Sipic, 2017), or indirect benefits through increased productivity or investment (Blackman et al., 2014; Haggar et al., 2017; Hidayat et al., 2015), others find limited or no such benefits (Glasbergen, 2018; Ibanez and Blackman, 2016; Jena et al., 2017).

Other studies address the national level. Lozano et al. (2010), using evolutionary game theory, suggest the long-run success of ecolabels will depend on the initial ratio of certified to uncertified firms in the industry when the ecolabel launches. Investigating the coffee sector, Grabs (2018) notes that heterogenous tastes in buyer countries and terroir in producer countries predispose the industry to fragmented certification. Deliberate institutional support also can successfully encourage environmental certification (Delmas, 2002; Marshall, 2009; Montiel and Husted, 2009; Wrana and Diez, 2018). Manning et al. (2012), for example, argue national institutions, such as coffee associations, can play critical roles in supporting sustainability certification, tilting the scales in favor of one certification option or another. Bartley (2010), conversely, points out that national-level institutions also can impede certification, detailing how forest tenure policies in post-Suharto Indonesia made Forest Stewardship Council certification almost impossible.

Yet other work investigates how global value chains interact with local contexts to affect certification (Lambin and Thorlakson, 2018). Prakash and Potoski (2006), for example, provide evidence that firms use sustainability certification as a way to signal quality to buyer markets in conditions of weak governance. Schleifer (2016) compares the relative success of sugarcane and soy certification in Brazil, arguing that as the Chinese market, less concerned about certification, became a more attractive option for Brazilian producers, sustainable soy production in the country foundered. Investigating the spread of voluntary carbon offset programs, Andonova and Sun (2019) find evidence that a combination of international institutional connections and supportive local environments facilitate projects' growth.

3. Sustainability certification in the wine sector

Wine production's environmental externalities include water use, waste generation, greenhouse gas emissions, chemical consumption, and land-cover change (Christ and Burritt, 2013). Several studies document increased willingness to pay for sustainable wines (Pomarici et al., 2018; Schäufele and Hamm, 2017, 2018; Sellers-Rubio and Nicolau-Gonzalbez, 2016), though this may not be the case for higher-value vintages (Delmas and Lessem, 2017). In response, some wine-producing regions have turned to sustainability as a marketing strategy (De Marchi et al., 2013; Hughey et al., 2005; Ponte and Ewert, 2009; Szolnoki, 2013), and New World wine regions have found the strategy particularly attractive (Szolnoki, 2013; Zucca et al., 2009). To be credible, however, producers have to have a way to successfully and simply signal their sustainable practices to consumers, differentiating themselves from the rest of their sector (Gallemore and Jespersen, 2019). Sustainability certification can be an attractive solution, sending low-bandwidth signals to customers and consumers.

While effective low-bandwidth information flows are necessary for certification to act as a meaningful transnational market signal, there is evidence high-bandwidth connections can facilitate sustainable practice diffusion among wine producers themselves. Lack of knowledge and skills often impede sustainable practice adoption (Szolnoki, 2013; Signori et al., 2017), but adoption rates are higher among more socially connected producers (Annunziata et al., 2018; Hillis et al., 2018). Cusmano et al. (2010), attribute some sustainability growth in New World wine countries, including Chile, to institutional cooperation between wineries and research communities. The Lodi Winegrape Commission, a local growers' organization, for example, boosted sustainability efforts in California's Lodi region (Ohmart, 2008). Indeed, many wine sustainability certifications grew from regional industry initiatives (Moscovici and Reed, 2018).

Following our arguments about the geography of high-bandwidth flows, which we expect to affect certification diffusion, we propose the following hypotheses:

- **H1:** Uptake of national sustainability certification in Australia and Chile's wine sectors will be spatially clustered.
- **H2:** Uptake of national sustainability certification in Australia and Chile's wine sectors will decline with travel time to the headquarters of the organization overseeing the certification.
- **H3:** Local outreach by the organization overseeing the certification will lead to higher rates of certification.

4. Methods and data

4.1. Study areas

Australia and Chile, the highest-exporting New World wine producers, accounted for about 3% and 2.5% of global production, respectively, in 2000, but around 5% and 4% by 2016 (International Organization of Vine and Wine [OIV], 2017). In 2009, the Winemakers' Federation of Australia started its Entwine program, while Wines of Chile issued its National Sustainability Code in 2011 (Wines of Chile, 2010). Australia exported 700 million, and Chile, 800 million liters, as

of 2014 (International Organization of Vine and Wine [OIV], 2017). In fiscal year 2015–2016, Australia exported 61% of its total production volume, primarily to China, the US, the UK, and Canada (Wine Australia, 2017a). Chile exported 80% of its 2014 production (Hennicke, 2015), mostly to China, the US, the UK, Japan, and Canada (Buzzetti Horta and Banfi Piazza, 2017). Following a period of industrial concentration starting in the 1990s, less than ten firms came to account for 61% of Australia's sales by volume by 2016 (WFA, 2018). Chile's industry is also concentrated: three holding companies accounted for half its 2016 production volume (International Organization of Vine and Wine [OIV], 2016; Viña Concha y Toro, 2016; Viña Santa Rita, 2016; VSPT Wine Group, 2016).

Yet the countries differ in geography and production diversity. Wine Australia (2017b) recognizes 65 wine regions, most of which have unique geographic indicators. Wines of Chile (2019c), only 25, with production concentrated in the Central Valley region and the Santiago-Valparaiso corridor (Overton and Murray, 2011). In Australia, red and white grapes account for roughly equal shares of crush tonnage (Wine Australia, 2018a, p. 3). In Chile, reds compose almost 70% of production (Hennicke, 2015). Finally, Australia counted about 2250 wineries in 2018 (Wine Australia, 2018b), Chile, only 275 (León and Carmine, 2012).

4.2. Interviews and coding

In order to develop a clear understanding of national sustainability certification, the first and second authors combined qualitative document analysis and semi-structured interviewing. Following an initial analysis of key industry-wide sustainability documents, they interviewed 25 wine-firm sustainability managers and 4 industry experts (12 firms and 1 expert in Australia and 13 firms and 3 experts in Chile). Interviews lasted from 30 min to one hour, were in the respondents' native language and, with their permission, were recorded and transcribed. The first two authors identified a first round of interviewees following in-depth secondary research on the wine industries in the two countries, focusing on key figures in the field. From there, they used a snowball sampling approach to identify further firms involved in sustainability. They also attended relevant industry events, leading to interviews with representatives from a range of firm sizes.

The number of potential interviews was limited by funding and time available for fieldwork, as well as the willingness of potential interviewees to participate. Our objective in this case was to develop an understanding of how the sustainable wine sectors in these two countries developed and operated, as a way to deepen and contextualize our hypotheses, which were then tested using quantitative methods. As the objective was not to create a representative sample of interviews across both sectors, we do not subject the interviews to statistical analysis. Rather, we view the primary issue to be whether or not we hit saturation - that is, whether or not subsequent interviews were yielding additional significant information on the issues of interest. In both cases, we hit the point of saturation.

Because of our interest in identifying certification drivers and tracing the history of national certification in each country, interviews prioritized firms active in sustainability. In Australia, 11 wine-firm interviewees were certified under one of the several sustainability standards used in the country. In Chile, 11 of the 13 wine-firm interviewees were certified under the National Sustainability Code and the other two were in the certification process. To ensure comparability, the first two authors each coded five interviews, identifying additional codes from the transcripts. They then compared, coordinated, and clarified their code definitions before recoding the first five interviews with the complete code set and then proceeding to code the remaining transcripts.

4.3. Spatial data collection and analysis

Because the certification systems and data availability for quantitatively testing hypotheses about environmental certification diffusion in the two case-study countries differ, we adopted different, but comparable, data collection strategies, which we describe individually below.

4.3.1. Australia

Australia's Entwine certification can take place either at the level of the winery or the vineyard, but vineyards account for the vast majority of certified entities. The third author built a database of certified and uncertified vineyard and winery locations using several websites with overlapping lists of Australian vineyards and wineries (Halliday Wine Companion, 2019; Visit Vineyards, 2019; WineBoss Australia, 2019), using fuzzy text matching and manual inspection to eliminate entries duplicated across sources, compiling a list of wineries and vineyards geolocated at the field, building, or municipal level of precision. We then consulted Entwine's online membership list (AWRI, 2019), matching members to wineries and vineyards identified in our assembled database. Because Entwine members are listed only by their legal names, identifying and locating operations was challenging. We conducted web searches to find evidence either assigning to operations in our winery and vineyard database or, if they were not yet in our database, to locate them. In this way, we were ultimately able to assign locations to 259, or approximately 60%, of the 432 Entwine operations listed on the organization's website as of 17 January 2019. While the inability to locate all listed members lowers our tests' statistical power, we see no particular reason our measurement error would be correlated with Entwine's geography, so we doubt this undermines our sample's representativeness. Ultimately, we found locations for 4904 vineyards and wineries.

We used these data to address two related, but separate, questions. First, we tested for geographic diffusion using logistic regression models predicting whether or not a vineyard or winery was an Entwine member. Our first explanatory variable, used to test hypothesis H1, measures the local concentration of certification as the proportion of operations within a defined distance that are certified. Because we had no a priori expectations about the appropriate distance, we calculated this measure for 10-, 25-, 50-, and 100-kilometer buffers around each operation, using the area under the receiver operating characteristic curve (AUC; see below) for model selection. Our second explanatory variable, used to test hypothesis H2, is travel time from the headquarters of the Australian Wine Research Institute, the organization overseeing the Entwine standard. We used the Google Maps API to compute the estimated travel time, in minutes, at noon in central Australia on Wednesday 7 March 2019, from each winery or vineyard location to the AWRI headquarters in Adelaide. Our third explanatory variable, which unfortunately is only available for Australia, tests hypothesis H3, and is a measure of AWRI's institutional footprint across the country. AWRI is a member of Australia's National Wine Extension and Innovation Network (2019), which maintains a calendar of events archived since 2012. AWRI workshops and other events, along with their locations, have been consistently posted on the calendar, so we were able to use these records to determine how many AWRI-sponsored events and AWRI-event-hosting locations were found within the same distance buffers as used for local certification concentration, again, using the AUC for model selection.

We included a variety of control variables to address potential confounders. First, we controlled for the straight-line distance between each vineyard and the closest of the five largest Australian cities, by population. We estimated models with linear, quadratic, and logarithmic versions of this variable, selecting the form that maximized the AUC. Firm size should influence certification rates, though existing studies dispute the expected direction of this relationship (Gabzdylova et al., 2009; Hughey et al., 2005), so we also estimated a model

controlling for the natural logarithm of one plus the operation's area in hectares, collected from Halliday Wine Companion (2019).

We also used join count statistics to test for spatial clustering. Join counts are computed by assigning each observation a set of neighbors (we define neighborhoods as all wineries or vineyards within 25 km) and counting the number of neighbors sharing a characteristic, in our case certification or non-certification. We tested for higher clustering rates than expected by random chance by permuting the certification variable 10,000 times, calculating the statistic for the permuted datasets to create a null distribution against which to compare our observed statistic value.

4.3.2. Chile

Unlike Australia, Chile's national certification system certifies firms, not locations. Here, the third author constructed a database of winery locations by combining membership rosters from Wines of Chile (2019a, 2019b), the largest national wine industry association, and the Movimiento de Viñateros Independientes, or MOVI (2019), an association of independent winery operations. In addition to these sources, we consulted numerous websites selling Chilean wines abroad, using these to find additional wineries.

In contrast to Australia, sustainably certified Chilean wineries were readily identified using trade and brand names. Lacking public location databases, however, we had to identify locations individually. The third author visited the websites of each winery found using the techniques outlined above, identifying the primary business address and, if one was present, the firm's Santiago office address. In cases where only vineyard locations and a Santiago office were provided on the website, we assumed the Santiago office to be the firm's primary business location. In the few cases where only vineyard locations were available and these vineyards were located in the same region, we estimated the firm's business location as the vineyards' centroid. We located 187 wineries, of which 58 were certified under the national Sustainability Code, 78.4% of those listed as certified (Wines of Chile, 2019a).

As with Australia, we were interested both in diffusion and in spatial clustering and used the same statistical methods. Our first explanatory variable, as in Australia, tests hypothesis H1 using the proportion of firms located within 10-, 25-, and 50-kilometer buffers that were certified, with the highest area under the ROC curve used for model selection. For our second explanatory variable, used to test H2, we computed the estimated travel time, in minutes, from each winery's main business location to Wines of Chile's Santiago headquarters, as this is the organization overseeing the national standard. We estimated travel time as of noon on Wednesday 13 February 2019, using the Google Maps API. Because Chile's certification system focuses on wineries, area was a less appropriate measure of resources for our logistic regression model than in Australia. Instead, we used membership data to proxy resources and market strategy. Because Wines of Chile's members tend to be the largest wineries in the country, we included a binary variable indicating wineries' membership in the organization. Because MOVI is open only to independent producers, we included a binary variable for MOVI membership to indicate smaller operations. Finally, because the wineries that are most focused on export markets tend to have offices in Santiago, we included a binary variable indicating whether or not a winery has a Santiago location. As in Australia, we also analyzed join counts with 25-km neighborhoods.

4.3.3. Statistical estimation

We conducted all statistical analyses in R 3.5.1 (R Core Team, 2018). We estimated logistic regressions with robust standard errors clustered by state in Australia and MOVI and Wines of Chile membership in Chile using the rms package (Harrell, 2013). To assess model fit, we computed the area under the receiver operating characteristic curve (AUC) using the pROC package (Robin et al., 2011). This measure, bounded between 0 and 1, measures the degree to which the predicted probabilities from the logistic regression model correctly predict whether or not an observation is or is not certified. A value of 0.5 would be expected at random chance, while 0.75 is generally considered a moderate and > 0.8 a quite good model fit. To compute our join count analyses, we used the spdep package (Bivand et al., 2013). We present summary statistics for all modeled variables in the Appendix.

5. Results

5.1. The state of certification in Australia

The Australian wine industry features four governance organizations with differing but complementary roles. The first, Wine Australia, is a public-private partnership focused on marketing and funding research and development. Its mission is to build and protect Australian wine as a brand (Wine Australia, 2018a, 2018b). The Australian Wine Research Institute (AWRI), the second major organization, is a private association focused on applied research and education (AWRI, 2019). The Winemakers' Federation of Australia (WFA) is a trade association that takes an interest in environmental issues (WFA, 2018). Australian Vignerons, the final major organization, acts as an industry representative for grape growers (Australian Vignerons, 2018). These organizations emerged from government- and industry-supported consolidation, in the 1980s and 1990s, of a cacophony of regional and other associations (Anderson and Aryal, 2015; Marsh and Shaw, 2000; WFA, 1996; Wine Australia, 2016).

WFA (2015) argues that Australia's supportive institutional environment means retailers in importing countries are more concerned about environmental than labor or social standards. Entwine, the country's national sustainability standard, correspondingly, has an environmental focus. Established by the WFA in 2009 (WFA, 2013), Entwine emerged from a process starting with discussions at the first National Wine Industry Environment Conference and Exhibition, held in Adelaide in 2000 (Jones, 2002). This led to the Australian Wine Industry Stewardship (AWIS) project, started in 2004 to provide annual updates on nationwide environmental practices (WFA, 2009). Several regional initiatives emerged around the same time, most as best-practice guidelines, rather than certifications. Responding to perceived market demand, WFA took a lead in developing Entwine as a national certification system (WFA, 2013).

Entwine features reporting requirements but lacks its own certification scheme. Instead, members must already be certified under Freshcare Environmental Viticulture/Winery Code of Practice, ISO-14001, or Sustainable Australia Winegrowing (SAW). Based in Australia and applied to the fresh produce industry, Freshcare was the first certification Entwine accepted. WFA worked with Freshcare to tailor its code to viticulture and wineries, completing these standards in 2009 (Freshcare, 2019). Early on, > 90% of Entwine members were Freshcare certified (WFA, 2013). ISO-14001 was the second standard Entwine admitted, though its relatively high costs put it out of reach for some smaller operators (Hughey et al., 2005). While Entwine only began to it in September 2017 (WFA, 2017), SAW actually is older than Freshcare, originating in McLaren Vale, near Adelaide, in the 2000s, and counting 129 members in the 2017/2018 season (McLaren Vale, 2018).

As of January 2019, Entwine's website listed over 400 members (AWRI, 2019). Because major wineries worked to enroll all their suppliers soon after the program began, grape growers account for over 90% of the membership (WFA, 2013, 2015). Indeed, as one interviewee argued, the initiative was primarily driven by larger firms, who "wanted some minimum standard so […] it made it easier for them to buy from people who have authenticity […]." As the interviewee went on to note, "there's a lot of small producers who haven't got the capacity or the resources to be part of it." These sentiments were echoed by other interviewees. One, for example, explained, "the only reason I was part of the Entwine program is that [a customer] said it was a requirement." Another said that "big groups are more and more asking for

environmental credentials. So that's why we've decided to go down the path of being Entwine-certified." Still, of the nine largest wineries in Australia in 2016, only five, about 29% of 2016 sales by volume, were Entwine members as of January 2019 (AWRI, 2019; EuroMonitor, 2017).

Of 12 winery representatives interviewed in Australia, 10 reported adopting certification because they were interested in sustainability for its own sake, though seven also said business interests motivated their certification decisions. In addition to meeting current customers' demands, one interviewee opined that "you would hope that at some point [certification] would be useful in marketing" and another thought certification "would be easier to communicate to consumers and supermarkets." Overall, nine interviewees identified a link between sustainability and profitability, either already early in the process or later on. For some, this was about savings, while for others, it could have to do with "consumer affection to what we do, […] rewarding us by buying our wine and paying a very high price."

Despite these relatively positive attitudes toward sustainability and certification, indicating receipt of low-bandwidth signals favoring these practices, several interviewees regarded Entwine itself skeptically. Two, for example, were certified under SAW but not Entwine; one was unaware of the program, and another argued Entwine was "not a program in my viewpoint. It's a membership from […] an industry body." Only two Entwine members interviewed used its logo on marketing materials. Another mused, "I don't think any consumers know what it is anyway. […] [I]f I hardly understand the program, how would a wine consumer […]?"

These responses are consistent with other evidence suggesting weak institutionalization of sustainability certification. When asked to list key organizations influencing sustainability in Australia's wine industry, interviewees listed numerous organizations, with little overlap. These included the McLaren Vale Grape Wine and Tourism Association (2 interviewees), AWRI (3 interviewees), WFA (2 interviewees), Wine Australia (1 interviewee), and the South Australian Wine Industry Association (1 interviewee). While three respondents referred to government initiatives and funding in the late 2000s that supported sustainability, others were skeptical. One argued that "the government is not sure what it wants to do and so there is no direction […], so the industries are left up to their own devices to work out which way they want to go," and another that "the national government has no leadership about sustainability."

Interviewees were aware of the challenges of institutionalizing national-scale sustainability certification. One admitted, "[W]e've probably ended up in a place that's not very desirable [.. .] we've had mixed messages here in Australia, which hasn't helped our marketing internationally. And we've ended up […] with these multiple programs." As another noted, "There's less than a handful of regions who very proactively go out and market […] sustainability, but in those regions it's very, very strong. In other regions, they don't have the capacity." "Account[ing] for the differences across those different regions," the interviewee pointed out, is "one of the most challenging things about managing a national sustainability program in Australia."

5.2. The state of wine certification in Chile

By contrast, the institutionalization of sustainability certification in the Chilean wine industry has been surprising even to participants. As one interviewee remarked, "If you had told me that in five or six years more than 75% of the wine exported will be from certified wineries [.. .] I would have never expected that." Like in Australia, Chile's major governance organization, Wines of Chile, emerged, in 2007, as an agglomeration of pre-existing associations (Wines of Chile, 2010). By 2018, it counted 75 members out of approximately 275 wineries (León and Carmine, 2012; Wines of Chile, personal communication, 2018). According to a 2010 strategic plan, the organization's goal is for Chile to become the "Number One producer of premium, sustainable, and diverse wines of the New World by 2020," emphasizing exports, improving the country's brand image, and boosting research and development (Wines of Chile, 2010, p. 6). It maintains close industry connections through staff from many wine firms who serve on its various committees and frequent meetings and workshops that bring wineries' sustainability managers together.

Wines of Chile maintains the Chilean Code for Sustainable Wine Production, also called the National Sustainability Code, a voluntary standard established in 2011 using biannual certification audits (Consorcio and Vinos de Chile, 2011). Its Sustainability Program supports research and education to help wineries get certified (Consorcio I + D Vinos de Chile S.A., 2018). As two interviewees recounted, the Chilean Code grew from a project at the University of Talca to adapt a Californian sustainability code to the Chilean context. Wines of Chile eventually took the project over, with input on social issues from the Catholic University of Valparaiso. All three of Chile's top holding firms and their subsidiaries are certified under the Code (Wines of Chile, 2019a) as, based on the interviewees' estimates, is as much as 60% of total production. In contrast to Schouten and Bitzer's (2015) contention that Southern sustainability standards target different audiences than Northern standards, the Chilean Code appears very clearly to be focused on the same international audiences as other certification standards in the wine industry, though it does seek legitimacy among Chilean producers by branding itself as a locally relevant approach.

Similarly to Australia, the vast majority of wine-firm interviewees (12 of 13) stated their own preferences as reasons to undertake sustainable practices, while only four mentioned a business case for doing so. Also similarly to Australia, the vast majority of wine-firm interviewees (12 of 13) justified certification based on a business case, a result similar to Oyaneder and Valderrama (2016). Generally, these justifications had to do with market access. One, for example, said, "If everybody is requesting it and many of our clients ask us, let's certify ourselves." Another that "we have all the certifications of the ISO that some markets require […]. We have different certifications because the markets ask us." As in Australia, this suggests some low-bandwidth signaling demanding more sustainable practices.

In contrast to Australia, the majority (9 of 13) of wine-firm interviewees mentioned certification's branding benefits, with eight having to do with "demonstrat[ing] with a quantified and scientifically based measurement that you have something." Another interviewee argued that "the stamp of sustainability […] is recognized abroad," while yet another argued, "[W]hen you get a certificate there, it gives you added credibility on the international scene. Especially with the bigger players, like the bigger supermarkets, or some of the bigger importers. It became a sort of evil necessity."

On the other hand, however, there was some skepticism of certification's value for information feedback. Seven wine-firm interviewees reported being unaware of pecuniary benefits from sustainability. One reported that "for a time [sustainability] was not profitable; for a long time the numbers were not positive for shareholders." Sustainability was "not a plus" when it came to the prices commanded in the market. Similarly to Australia, few respondents were interested in using the Wines of Chile label in marketing, a few because they "do not like to use sustainability as a marketing tool" and others because they did not believe the logo to be well recognized or accepted.

Whereas interviewees in Australia struggled to explain why sustainability had emerged as an issue in the industry, every interviewee in Chile had an explanation, and 12 of the 13 mentioned Wines of Chile as a key influencer, compared to only two mentioning the government. Interviewees characterized the Chilean Code as "born out of mutual ownership, both as an opportunity that we saw to reach new markets and also because of a philosophy that the winery wanted to adopt." Another said, "it was always a public and private contribution." Another, that "Wines of Chile […] created [the Code] together with professors, together with researchers," though "more than anything it was, I believe, an initiative of businesspersons." Interviewees saw the

program as a response to demand for sustainability certification and as "a vision more than anything to differentiate Chilean wine from other countries," some of which were developing their own sustainability standards.

Interviewees reported a generally quite high level of national-scale cooperation, "very good relationships," and "positive synergy" among key players in the Chilean wine industry. Partially, this seems to result from a sense of common fate. One interviewee, for example, argued that "showing a cohesive industry around […] sustainability […] helps us all. And more than competing among us, here internally, our competition is outside." Wines of Chile, similarly, argues the National Code serves not to differentiate Chilean wines from each other, but to distinguish them from foreign competitors. As one interviewee explained, "In Germany, for a consumer who goes to the supermarket to buy a wine, I think it is not so normal to say, 'I buy a Santa Rita wine or a San Pedro,' but they say, 'I buy a Chilean wine or an Argentine wine." Wines of Chile encourages this view, promoting the Code at several major international wine fairs (Revista Certificación, 2017). Member firms also have incentives to promote the standard. One interviewee, for example, reported his general manager promoting the code at European tradeshows. Efforts in Chile, in other words, are tuned to providing a trustworthy low-bandwidth signal to consumers that Chilean wine is sustainable.

5.3. Comparing certification geographies

Figs. 1 and 2 show locations of a sample of wineries and vineyards in Australia and wineries in Chile. In both maps, locations not using the national standard are presented in black, whereas locations using the national standard in white. The Australian and Chilean wine industries have distinct geographies. Because Australia is longer on its east-west than its north-south axis, more regions are amenable to wine production than in Chile, whose north-south orientation encompasses considerable climatic diversity. Only a small zone, centered roughly around Santiago, the country's capital and largest city, is amenable to viticulture. Whereas Australia has numerous separate wine production clusters, Chilean production is centralized.

Using join counts for 25-kilometer neighborhoods, we find a statistically significant clustering of operations using the national sustainability system in both countries. In Australia, there are clearly visible clusters of certified operations, particularly near Adelaide and the McLaren Vale on the eastern side of the Great Australian Bight, and in southwestern mainland Australia. Operations using the national Sustainability Code are more evenly distributed in Chile, though they, too, exhibit statistically significant clustering.

Tables 1 and 2 present logistic regression models predicting whether or not an operation uses the national sustainability standard. We estimate several models for Australia because some of the explanatory variables are correlated, though not at levels generally leading to problems of multicollinearity, and because of the substantial decline in observation numbers when including measures of operation size. Based on the AUC, we have reasonably good model fits. In all models, as expected under Hypothesis H1, we find a strong positive relationship between local certification rates and the probability the operation is an Entwine member, though the buffer distance giving the best fit differs across model specifications. Also in all cases, except when controlling for operation size in Australia, we find significant negative associations between travel times to sustainability certification organizations - AWRI and Wines of Chile - and the probability that an operation is using the national sustainability system, as expected under Hypothesis H2. In Australia, we predict each 1% increase in travel time to be associated with a 0.5% reduction in the odds that an operation is an Entwine member. For an increase in travel time to the AWRI's Adelaide office from 1–2 h, for example, we would expect the odds that an operation is an Entwine member to decrease by approximately one third. Finally, in all cases, we find that our measures of AWRI institutional

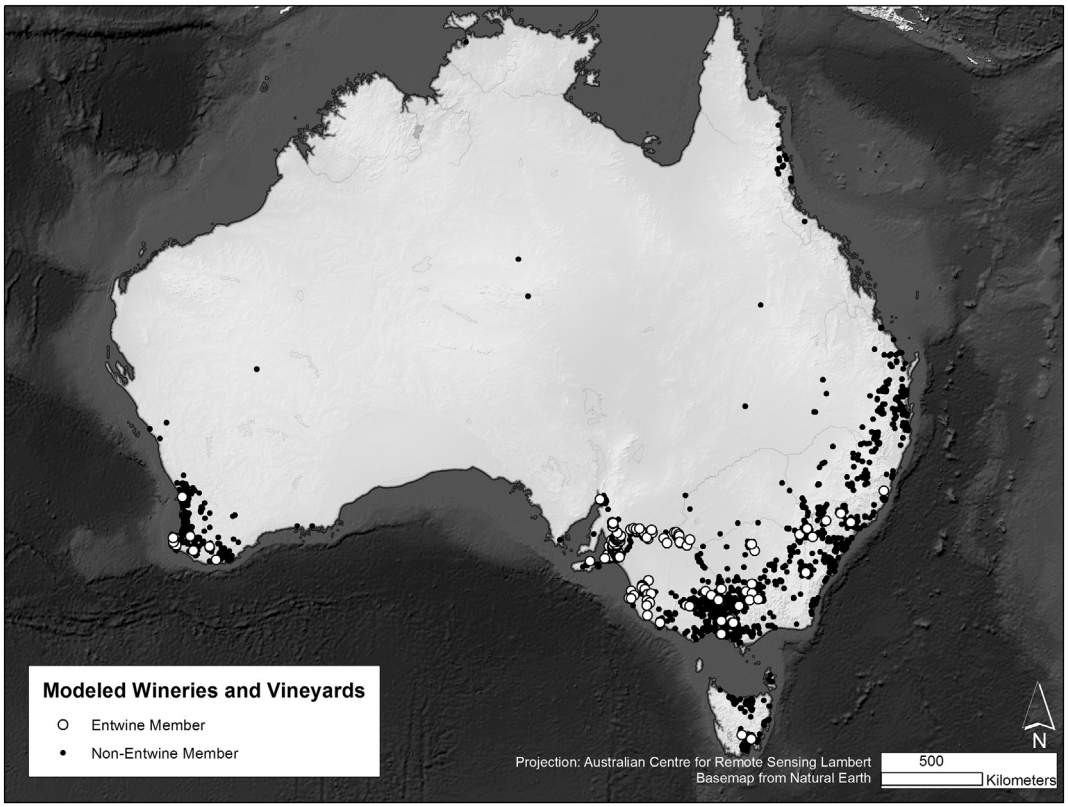

Fig. 1. Entwine and non-Entwine member wineries and vineyards located using the data collection method outlined above. Join count for Entwine members at 25-kilometer neighborhoods: 2006. Mean of 10,000 permuted simulations: 892. Variance of simulations: 8543. $P < 0.001$.

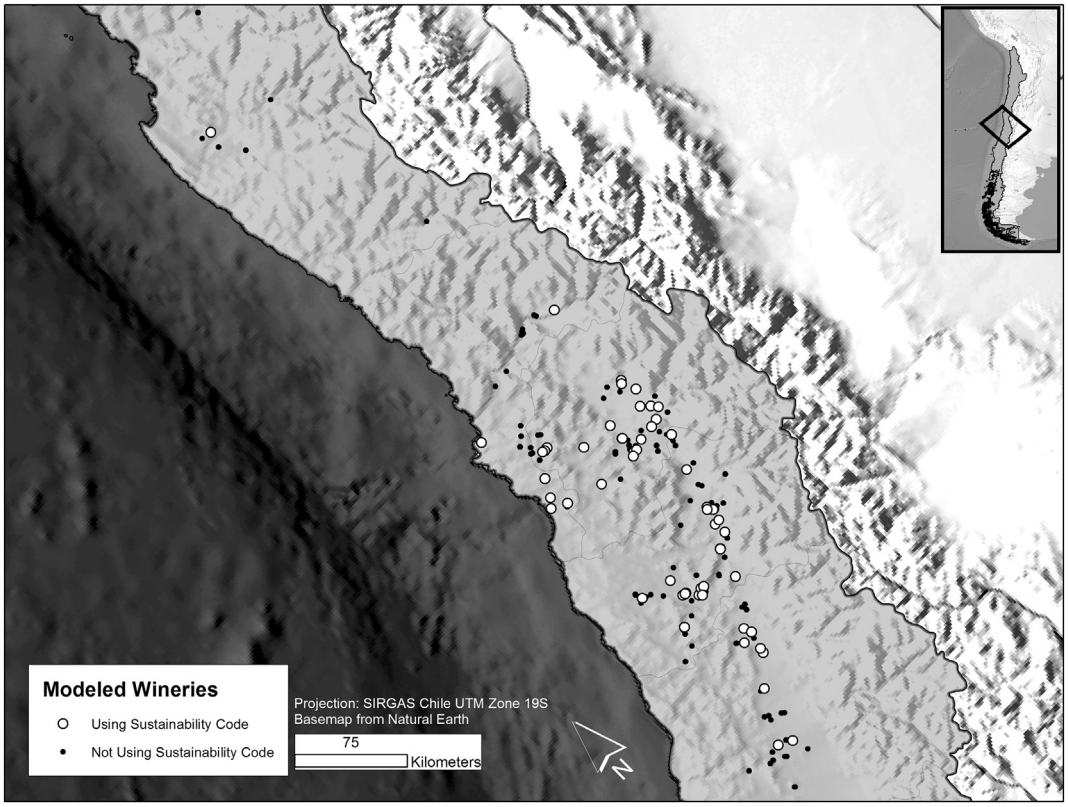

Fig. 2. Wineries using and not using the Chilean Code for Sustainable Wine Production located using the data collection method outlined above. Join count for Sustainability Code users at 25-kilometer neighborhoods: 184. Mean of 10,000 permuted simulations: 145. Variance of simulations: 231. $P = 0.012$.

presence are strongly associated with certification, as expected under Hypothesis H3. Controlling for operation size, for example, each additional AWRI activity location within 10 km is associated with an approximately 23% increase in the odds of certification. In the model without operation size controls, this declines to approximately 4%, though it is notable that in this model (Model 3) the effect of travel time to AWRI headquarters is much stronger.

In Chile, very interestingly, we do not find a statistically significant relationship between Code use and the proportion of certified wineries in an operation's neighborhood, as expected under Hypothesis H1. With regard to Hypothesis H2, our results for Chile are similar to those for Australia, though the negative association between accessibility and use of the national standard is even more pronounced. An increase in travel time to the Wines of Chile office from one to two hours, for example, is estimated to result in a 44% decline in the odds a winery applies the Chilean Code. Due to a lack of available data on Wines of Chile activities across the country, this model does not include a test of Hypothesis H3.

We also find the expected relationships between operational size and Code use, with Wines of Chile members being more and MOVI members much less likely to be using the code. Surprisingly, controlling for these other factors, we find a negative relationship between having a Santiago office and using the Code, despite expectations that having a presence in the city constituted a strong signal of export interest. The absence of a significant negative association between presence in Santiago and Code use remained when we estimated an additional model (not depicted) dropping the Headquartered in Santiago variable.

6. Discussion

That national-scale sustainability certification is more advanced in Chile than Australia is at first surprising. These countries' divergent trajectories exist despite similar value-chain positions and the fact that, according to the World Bank's (2019) World Development Indicators, Australia's Gross Domestic Product per capita by purchasing power parity is roughly twice Chile's, while its Worldwide Governance Indicators scores are uniformly better (Kaufman et al., 2010). Relative affluence and institutional quality, two factors associated with the capacity to mobilize on environmental issues (Di Gregorio et al., 2017), and expected to be important in certification more broadly (Andonova and Sun, 2019), predict more effective institutionalization in Australia's wine industry, not Chile's. Nevertheless, our qualitative analysis suggests Wines of Chile has been particularly successful in constructing the high-bandwidth connections necessary for successful diffusion. Its institutional influence - and the perceived need to prove Chilean wine to importers - helps explain the widespread interest in its Code.

We find evidence in both countries that use of the national sustainability standard is more frequent near areas where the overseeing organizations can undertake outreach. While we find spatial clustering in certification, controlling for these and other factors, we interestingly do not find clustering in Chile. One possible explanation is that, for all practical purposes, Chile has only one wine production region, centered on Santiago, and patterns of adoption are adequately explained by distance from the city and Wines of Chile's institutional reach. In other words, there is a cluster, but the cluster is simply the entire wine region. In Australia, by contrast, where wine production is not contiguous, localized clusters are more important for diffusion. These patterns are consistent with expectations that diffusion would require high-bandwidth information flows, which are tough to maintain across distances without concerted institutional effort. With lower transaction costs and stronger branding incentives generating a sense of common fate, it likely is easier to institutionalize national sustainability certification in Chile than Australia.

To be clear, we do not contend geography is the single factor determining ecolabelling success, and both our quantitative and qualitative evidence identifies other factors that resonate with previous

Table 1
Logistic regression models predicting Australian wineries' and vineyards' membership in Entwine. Coefficients on log-odds scale. * = sig. at 0.05; ** = sig. at 0.01; *** = sig. at 0.001.

	Model 1	Model 2	Model 3	Model 4
Intercept	−5.33***	−7.25***	−3.48***	−4.78*
	(0.728)	(1.09)	(0.978)	(1.95)
H1: Proportion of entwine-certified operations within 50 km		8.31***		
		(0.826)		
H1: Proportion of entwine-certified operations within 25 km				1.78***
				(0.514)
H1: Proportion of entwine-certified operations within 10 km	3.07***		3.14***	
	(0.181)		(0.236)	
H2: Travel time to Australian wine research institute office (minutes, ln)	−0.753***		−0.686***	−0.150
	(0.0856)		(0.108)	(0.178)
H3: Australian wine research institute activities within 100 km		0.041***		
		(0.0056)		
H3: Australian wine research institute activity locations within 100 km			0.0398***	
			(0.0107)	
H3: Australian wine research institute activity locations within 10 km				0.205***
				(0.0436)
Operations within 100 km (ln)	0.733***	0.334*		
	(0.126)	(0.134)		
Operations within 50 km (ln)			0.263*	
			(0.0036)	
Operations within 25 km (ln)				−0.157
				(0.187)
Distance to nearest of the five largest cities in Australia, in Kilometers	0.0209***	0.0121***	0.0224***	
	(0.0025)	(0.0018)	(0.0036)	
Distance to nearest of the five largest cities in Australia, in kilometers^2	−0.000***	−0.000***	−0.000***	
	(0.000)	(0.000)	(0.000)	
Distance to nearest of the five largest cities in Australia, in kilometers (ln)				0.118
				(0.0684)
Hectares (ln)				0.689***
				(0.120)
N	4907	4907	4907	1904
Chi-squared	281.9***	253.2***	282.1***	133.7***
Pseudo-R2	0.165	0.148	0.165	0.210
AUC	0.781	0.777	0.784	0.829

Table 2
Logistic regression model predicting Chilean wineries' use of the Chilean Code for Sustainable Wine Production. Coefficients on log-odds scale. * = sig. at 0.05; ** = sig. at 0.01; *** = sig. at 0.001.

	Model 5
Intercept	−0.168
	(1.44)
H1: Proportion of certified wineries within 25 km	−1.64
	(1.70)
H2: Travel time to wines of Chile office (minutes, ln)	−0.816***
	(0.210)
Wines of Chile member	1.70***
	(0.0997)
MOVI member	−7.66***
	(1.00)
Has a Santiago office	0.997
	(0.692)
Headquartered in Santiago	−3.49***
	(0.001)
Wineries within 50 km (ln)	0.782***
	(0.221)
N	187
Chi-square	66.2***
Pseudo-R2	0.420
AUC	0.847

studies. At the operational level, like Diaz-Balteiro and García de Jalón (2017), we find evidence actors distinguish between certification and sustainability as such. Like Rivera et al. (2017), our comparison of Chile and Australia suggests that more homogeneity may facilitate collective action on ecolabelling. At the national level, the importance of Wines of Chile is consistent with Manning et al.'s (2012) reminder that national-level industry associations can have a significant effect on certification. At the global value chain level, we find evidence in Chile in particular that target markets play a very important role. Because our research design involved selecting two countries whose industries were similarly positioned in global value chains, however, we cannot easily make further empirical claims about this factor based on our work.

How, given the governance and resource constraints Chile faces relative to Australia, was Wines of Chile so much more successful than Entwine? While Entwine targets vineyards across numerous, diverse wine valleys, the Chilean Code certifies a less diverse region with fewer, less heterogeneous, actors. Building high-bandwidth connections is costly, but Wines of Chile is literally better positioned to do so than is its Australian counterpart. With most wineries having quick access to - or facilities in - Santiago, Wines of Chile can more easily be embedded in the industry through workshops, committees, and so on, facilitating diffusion.

It is difficult to assess the relative importance of geographic as opposed to industry ownership patterns in explaining certification uptake. The number of operators in Chile is much lower than in Australia, and this fact could explain the difference between the two. We believe three points are relevant here. First, as noted in the methods section, both countries have similar industry consolidation, placing them on relatively equal ground from a collective action perspective (Olson, 1965). Second, when we control for operation size, we still find strong geographic patterns in both countries. Third, the production structure in the case of wine is clearly affected by potential production regions' geographies. Grapes only grow in certain places.

Recently, work in the policy and academic literature suggests jurisdictional approaches might be an effective means of addressing environmental certification's shortcomings, particularly for transnationally traded deforestation-linked commodities (Boyd et al., 2018; Newton and Benzeev, 2018; Pacheco et al., 2017; Umunay et al., 2018).

Jurisdictional programs use governmental authority and resources to lower transaction and start-up costs, ensure enforcement, resolve tenurial conflicts, and promote coordination among disparate initiatives (Larsen et al., 2018; Meyer and Miller, 2015; Umunay et al., 2018). If high-bandwidth connections support complex innovations' diffusion, local governance efforts may be more successful than transnational governance alone. Indeed, we do find robust environmental certification in some clusters in Australia, particularly the McLaren Vale. As Perey (2014) argues, it may be beneficial to adopt a "fractal" approach. Building multiple hubs from which locally tailored sustainability programs could diffuse, might better use high-bandwidth local connections to promote broader institutionalization.

7. Conclusion

Sustainability is a growing concern in the wine sector. Comparing experiences in Australia and Chile, we find that, somewhat counter-intuitively, the institutionalization of national sustainability certification is more advanced in Chile than Australia. We argue that this difference can be attributed in part to geographic differences between the two countries, which make it more costly to build the high-bandwidth connections required for successful diffusion in Australia than in Chile. Finding evidence that sustainability certification is spatially clustered in both countries, we suggest geographic factors act as critical constraints on high-bandwidth connections. Considering the interplay between low-bandwidth and high-bandwidth information flows can support a clearer analysis of telecoupled systems' governance challenges, informing policy ideas like the call for jurisdictional environmental certification.

These considerations apply not only to environmental certification but potentially more broadly, to other "knowledge deficits" (Challies et al., 2019: 189–190) or "lost signals" (Hull and Liu, 2018) characteristic of telecoupled systems. While information from supply-chain transparency is increasingly available (Gardner et al., 2019), thinking about information flows in terms of bandwidth can help identify who needs access to what information, and what investments need to be made, in order to promote sustainable outcomes.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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