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MODELING THE COEVOLUTION OF RELIGION AND COORDINATION IN BALINESE RICE FARMING

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Culture often seems to exhibit a high degree of harmony or coherence, demonstrating various sorts of "fit" between cultural patterns in disparate domains. In this chapter, I explore one strategy for explaining some kinds of cultural coherence. I show how a gradual process by which individuals with different cultural variants influence each other could lead to such coherence. More specifically, I use computer simulations to model the spread of religious patterns specific to rice-growing regions in southern Bali. These cultural patterns show a high degree of coherence with Balinese beliefs about the natural world. I show that the religious patterns could have spread through cultural transmission biased by variation in harvest success, under the influence of local social and ecological conditions.

The simulations also highlight the potential importance of what we might call *population communication structure* in cultural transmission: in the simulations, the spread of certain religious cultural patterns was likely only when communication from distant farming regions occurred infrequently. This communication pattern allowed homogeneity in small regions to develop, creating pragmatic benefits that subsequently made religious practices in those regions attractive to individuals in other areas. This ability of partial isolation to preserve variation and to support group-beneficial effects is well known from evolutionary biology (e.g., Gillespie 1998; Godfrey-Smith 2009; W. C. Wimsatt 2002).[1] A great deal of research has been conducted on group-level effects in cultural transmission (e.g., Boyd and Richerson 2005), as well as on the effects of communication structure on cultural transmission (e.g., Alexander 2007; Atran and Medin 2008). According to some proposals, group-level effects have played an important role in the spread of certain religious practices (Norenzayan 2013; Norenzayan et al. 2016; Wilson 2002). The present research, however, illustrates a new way that explanations of harmonious cross-domain cultural patterns may be constrained by the effects of communication structure.

Shared-Culture and Gene-Culture Coevolution Traditions

Anthropologists often view a culture as something that is shared by all or most members of a society or by members of some group within it (e.g., Benedict [1934] 2005; Brown 2008; Descola 2005; C. Geertz 1973b; Lévi-Strauss [1962] 1990).[2] Although there is enormous diversity in the assumptions and methods of such "shared-culture" approaches, most anthropological research on culture probably falls within this category. Shared-culture approaches do not necessarily ignore the existence of cultural variation within a society (e.g., C. Geertz 1973b; Lienhardt 1961), but many anthropologists focus only on those variants that many individuals share. Some researchers, such as those who use *cultural consonance* methods, acknowledge a great deal of individual cultural variation but use statistical methods mainly to derive evidence of a shared core of culture that each person is able to report or embody to one degree or another (e.g., Dressler et al. 2005; Romney, Weller, and Batchelder 1986).

Research in what is known as the dual-inheritance theory or gene–culture coevolution (GCC) tradition has a different focus and often very different assumptions from shared-culture research. Rather than focusing on *a* culture as something that is common to many individuals, GCC approaches treat *cultural variants* (usually beliefs or other mental states but sometimes behavioral practices or artifacts) as attributes of individual persons. GCC approaches often focus on explaining cultural change within a population by investigating conditions that influence how cultural variants spread from individual to individual. The focus on cultural change is not unique to the GCC tradition; anthropologists working in shared-culture traditions sometimes discuss cultural change too, but when they do their focus is usually on large-scale patterns of change involving an entire society or large parts of it (e.g., Benedict [1934] 2005; Descola 1986; Lévi-Strauss [1962] 1990; Tsing 2005), rather than on ways that numerous individual interactions between many people produce this change.

Cultural Coherence

Within shared-culture traditions, culture is often presented as composed of a set of mutually interdependent, partly harmonious cultural elements. The ways in which cultural variants "cohere" varies, though. For example, Benedict ([1934] 2005) spoke of cultures as having coherent "personalities," and Lévi-Strauss ([1962] 1990) viewed many elements within a culture as conceptually complementary. Other authors implicitly describe cultures as relatively coherent by showing how certain elements of a culture are interdependent or mutually supporting (e.g., Descola 2005; C. Geertz 1973b; González 2001; Sanday 1981; Smelser 1993; Tsing 2005; W. C. Wimsatt 2002, 2014; Wimsatt and Griesemer 2007).[3]

I will talk of some sets of cultural patterns as "coherent." This idea is intentionally vague. At the most basic level, the well-known phenomenon of cognitive dissonance (e.g., Izuma et al. 2010) suggests that beliefs that are obviously contradictory, that seem unlikely to all be true, or that are simply emotionally difficult to hold at the same time will be less likely to be shared by most members of the society (which is not to say that it is impossible for contradictory sets of beliefs to be widely shared). Cultural patterns can include complex worldviews, so if cultural patterns from different societies were arbitrarily mixed together, the potential for contradiction, mere implausibility, and emotional discomfort due to conflicting values and ideas would be high. This suggests that there are at least very loose constraints on the elements of a culture that are likely to be found together. There seem to be more subtle kinds of cultural coherence as well, perhaps depending on relationships between cultural variants that involve social structure (Brown and Feldman 2009; Caporael 2014), emotional relationships involved in structured social interactions (Bourdieu 1966; Caporael 2014; C. Geertz 1973a), physical aspects of daily activities (Descola 2005; González 2001), aesthetic relationships (H. Geertz 2004; Lansing 2006), analogical and metaphorical relationships (Colby 1991; Dehghani et al. 2009; C. Geertz 1973b; Lévi-Strauss [1962] 1990; Sanday 1981; Thagard 2012; Tilley 2000), general psychological processes of association (Colby 1991), and various aspects of psychology and material culture that scaffold or facilitate learning certain cultural variants or facilitate certain behaviors (Abrams 2015a, 2015b; Kline 2015; B. H. Wimsatt 2014; W. C. Wimsatt 2014; Wimsatt and Griesemer 2007; chapter 1 of this book).

What I mean by coherence is thus quite broad, but I am particularly interested in those striking sorts of coherence that cut across disparate domains and do not immediately suggest a simple explanation. For example, Clifford Geertz (1973a) described patterns of betting behavior at Balinese cockfights. He argued that the cocks on which spectators bet and the amount of money put up reflected conflicts and alliances between various social groups whose members participated in the cockfight:

> What makes Balinese cockfighting deep is thus not money in itself, but what . . . money causes to happen: the migration of the Balinese status hierarchy into the body of the cockfight. Psychologically an Aesopian representation of the ideal/demonic, rather narcissistic, male self, sociologically it is an equally Aesopian representation of the complex fields of tension set up by the controlled, muted, ceremonial, but for all that deeply felt, interaction of those selves in the context of everyday life. The cocks may be surrogates for their owners' personalities, animal mirrors of psychic form, but . . . the cockfight is—or more exactly, deliberately is made to be—a simulation of the social matrix, the involved system of crosscutting, overlapping, highly corporate groups—villages, kingroups, irrigation societies, temple congregations, "castes"—in which its devotees live. And as prestige, the necessity to affirm it, defend it, celebrate it, justify it, and just plain bask in it . . . is perhaps the central driving force in the society, so also . . . is it of the cockfight. (C. Geertz 1973a, 436)

Geertz argues here that two very different cultural domains (relationships between social groups and betting in cockfights) exhibit structural parallels and that these parallels interact with patterns in underlying antagonisms, feelings of solidarity, and feelings about status common for men in Balinese society in the late 1950s. Other parts of Geertz's essay show how the Balinese cockfight exhibits harmony with additional dimensions of Balinese life. The essay thus provides a description of subtle relationships of coherence within a culture. Geertz's work has been both widely celebrated and widely criticized (Alexander, Smith, and Norton 2011; Brown 2008; Risjord 2007), and one might doubt whether people in any society exhibit so much psychological uniformity, but the passage provides a good illustration of what I believe has been shown by the body of qualitative ethnographic research as a whole: that subtle and complex relationships of "harmony" between cultural patterns in different domains are probably common in most societies.

GCC researchers sometimes endorse the idea that sets of cultural variants exhibit general coherence patterns (Richerson and Boyd 2005; Richerson et al. 1997). Given GCC's focus on the transmission of cultural variants between individuals, GCC researchers should take coherence to result partly from processes within and between individuals. Moreover, as suggested by the remarks above, research in cognitive science has investigated how certain thought patterns or behaviors make others more likely in an individual,[4] and it seems probable that relationships of this kind might also influence ways that different cultural variants do or do not tend to spread together within a population. However, GCC researchers have generally not made methods for investigating coherence relationships part of their focus. This is not surprising: While shared-culture researchers can easily focus on complex relationships between many cultural variants, ignoring or downplaying individual variation or focusing on only a few individuals, GCC researchers' focus on individual-level variation within populations makes the study of complex relationships between cultural patterns difficult. Some GCC-related research has looked at how adoption of some cultural variants hinders or facilitates the adoption of others,[5] but GCC researchers have rarely tried to move toward investigating the kind of subtle coherence relationships between cultural patterns that shared-culture researchers have described.

The research reported here attempts to take a small step in that direction, using simulations inspired both by the GCC tradition and by shared-culture research on subtle relationships between religious ideas, farming practices, and democratic institutions. My simulations extend those developed by Stephen Lansing and James Kremer (1993), which they used to support a hypothesis about how Balinese rice farmers came to coordinate planting and water use. Lansing's subsequent research on religious and social phenomena that interact with this coordination process motivated my simulations.

I provide a context for understanding both sets of simulations in the next section, describing Balinese farmers' sophisticated method of coordinating planting and water use and showing how Lansing and Kremer's simulations helped to explain its origin. This section also discusses Lansing's investigation of Balinese religious practices, which seem in some respects ideally suited to help maintain the institutions and practices that support the water coordination system. This is the example of cultural coherence that will be my focus in the chapter. In the following major section, I outline several hypotheses that might explain how the rice-growing regions came to have religious cultural patterns so tuned to the needs of growers. The simulation results reported following that provide support for one of these hypotheses: that success-biased cultural transmission explains the spread of religious patterns conducive to the rice grower's needs. However, the simulations also suggest that this kind of cultural transmission only makes the spread of such religious patterns likely when communication between different groups of people occurs rarely, albeit regularly. The penultimate section of the chapter notes ways that these constraints might be realized in a real society, discusses the advantages and limitations of my model, and explains why some of the alternative hypotheses mentioned below may also provide partial explanations of the spread of Balinese religious patterns. I also note that the common view that agent-based simulations should be simple in conception ought to be tempered. While simple simulations are often easier to understand, their typical focus on modeling abstract principles can keep us from discovering theoretical principles more easily noticed using somewhat complex simulations. The final section provides some summary remarks.

BACKGROUND

Balinese Rice Production

Rice growing on the southern slopes of Bali typically involves scheduling crops so that nearby fields lie fallow at the same time.[6] Otherwise, pests such as rats and insects easily move from fallow fields to those with growing plants, resulting in the unchecked growth of pests, and agricultural disaster. However, farmers depend on water flowing down the mountainside in rivers and canals, and there is usually not enough water for all farmers in the same watershed to plant simultaneously. There is thus a complex coordination problem: water management requires that planting schedules be staggered, while pest management requires that nearby fields, at least, have the same planting schedules.[7]

Balinese rice farmers have traditionally solved this problem as follows: Farmers are members of villages. Several villages and their residents are members of a single water temple, or *subak*. Groups of nearby subaks adopt the same planting schedule (see below). Each such planting schedule should, ideally, have fallow periods that differ from those of other groups of subaks sharing the same watershed. The result is a complex pattern of planting schedules, as illustrated in Figure 7.1, which shows Lansing and Kremer's (1993) map of subaks' planting schedules in two watersheds in Bali.

How did the Balinese develop this centuries-old crop-scheduling system? Schulte Nordholt ([1996] 2010, 2011) and Hauser-Schäublin (2003) argued that the system was the result of central planning by representatives of kings, beginning at least as early as the eighteenth century. We can call this the *central planning* hypothesis. Clifford Geertz (1981), followed by Lansing and his colleagues (Lansing 2006, [1991] 2007; Lansing et al. 2009; Lansing and Kremer 1993),[8] argued that the Balinese system emerged without central coordination and resulted from local decisions within democratically elected councils in subaks. According to this *distributed decisions* hypothesis, subaks do not need to confer with other subaks across an entire watershed in order to produce the kind of pattern of coordination observed.

Evidence produced in support of the central planning and distributed decisions hypotheses has come from historical documents, interviews, surveys, ethnographic work, and archaeological data. The distributed decisions position has a prima facie problem, however: Is it really plausible that such a complex system of coordination across the length of a watershed could arise from local decisions without any kind of global coordination? Using computer simulations developed by Lansing with an ecologist, James Kremer, Lansing argued that it could (Lansing 2006, [1991] 2007; Lansing and Kremer 1993).

The Lansing-Kremer Model

Lansing and Kremer's (1993) agent-based computer model treats each subak as an individual "agent" that makes a decision every year about which planting schedule to adopt. These planting schedules allow different rice varieties to be grown in various orders with different fallow months. Subaks are arranged in two watersheds based on the actual arrangement of subaks along the Oos and Petanu Rivers in Bali (cf. Figures 7.1 and 7.2), and the model tracks the effects of upstream subaks' planting schedules on downstream subaks. (Subaks use more water when their rice is growing.) The model also tracks pest growth and movement and the effect of pests on harvests. In Janssen's (2012) model, which is based on Lansing and Kremer's (1993) original model, some subaks are *pest neighbors*. Pests can only travel between pest neighbors, and thus the model isolates pests within clusters of subaks. (This idealization was relaxed in some of Lansing's later models, such as those presented in Lansing et al. [2009, 2017], producing similar results to the original Lansing–Kremer model without assuming impassable barriers to pest movement.)

Initially, each subak is assigned a random planting schedule (a sequence of rice varieties and fallow periods along with a starting month). Water flow, rice growth, pest growth, and pest movement are tracked in each timestep, which represents one month. At the end of the year, each subak reassesses its crop schedule according to the following rule:

Figure 7.1. From Lansing and Kremer (1993), Figure 10. Lines represent rivers or canals. Icons represent subak locations. Icon shapes represent planting schedules of subaks at the time of Lansing's study.

> If any of our pest-neighbor subaks has a better harvest than we do, adopt their planting schedule in the coming year.

Lansing's hypothesis was that this simple, wholly local process would lead to the kind of pattern of global planting schedules that has been found to be used both currently and historically.

Indeed, though each run of a Lansing–Kremer simulation differs in details, after twenty to one hundred modeled years, the simulation always settles into a state qualitatively similar to observed arrangements of planting schedules in subaks in the Oos and Petanu watersheds. Figures 7.2 and 7.3 illustrate this relationship using a version of the Lansing–Kremer model: Figure 7.2 shows the initial state of one run of the model, and Figure 7.3 shows the configuration of planting schedules in the same run after fifty years (six hundred time steps).[9] Each gray icon represents a subak, arranged roughly as actual subaks are arranged within the two watersheds. A gray line between two subaks represents the fact that they are pest neighbors: pests are able to travel between them, and each subak will compare its harvest with the other's at the end of the year. Subaks' shapes represent their sequences of rice varieties, and the direction of black pointers represents the month in which the sequence is started.[10] Although planting schedules are initially random, after fifty years, planting schedules are identical within most clusters of connected subaks. Compare this modeled arrangement after fifty years (Figure 7.3) with the empirical arrangement (Figure 7.1).

The simple rule stated by Lansing is thus capable of generating the sort of planting schedule patterns that Balinese rice farmers actually use. The rule is also intended to choose a pattern of planting schedules that will effectively trade off water needs versus pest suppression. In the simulation, the average harvest always increases after an initial settling period, although some runs result in better average harvests than others.[11]

Lansing and Kremer's model provides a "how-possibly" explanation (Brandon 1990)[12] of the origin of water coordination: it shows that the postulated mechanism is capable of generating the phenomenon of a certain kind of planting schedule pattern, with improved harvests. Lansing has provided additional evidence showing that this mechanism is more than a merely possible explanation, though. This evidence includes interviews, surveys, historical texts (Lansing 2006, [1991] 2007; Lansing and de Vet 2012), and other data sources, including genetic evidence for a more complex hypothesis about the gradual spread of the subak system (Lansing et al. 2009).

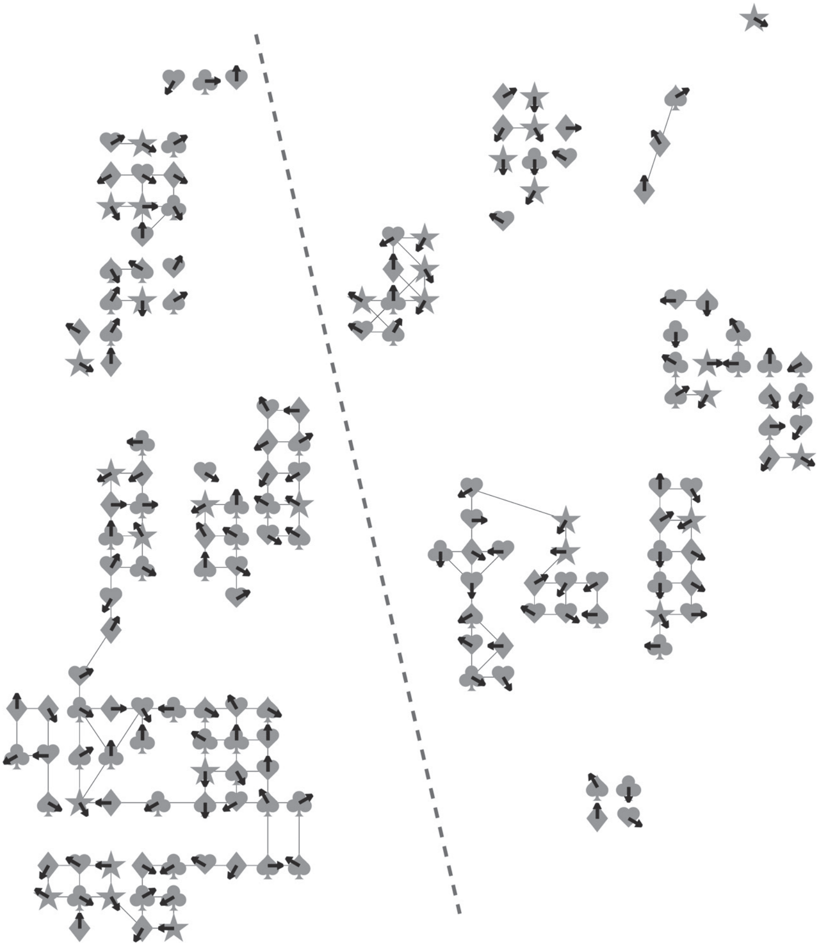

Figure 7.2. Initial random state from one run of BaliPlus, a modified version of Janssen's (2012) reimplementation of Lansing and Kremer's (1993) model, running in a configuration that reproduces the original behavior of Janssen's model. Each gray icon represents a subak, and solid gray lines connect pest neighbors. *Icon shape:* Rice variety sequence. *Pointer direction:* Month the sequence is started. *Dashed line:* Division between watersheds.

As mentioned above, critics such as Schulte Nordholt ([1996] 2010, 2011) and Hauser-Schäublin (2003) have argued for a different view, but all things considered, Lansing's view appears most plausible at this point. Tracking cultural history is always difficult, however.[13]

Note that though Lansing developed this model outside the GCC tradition, it is a cultural transmission model in which the cultural variants are

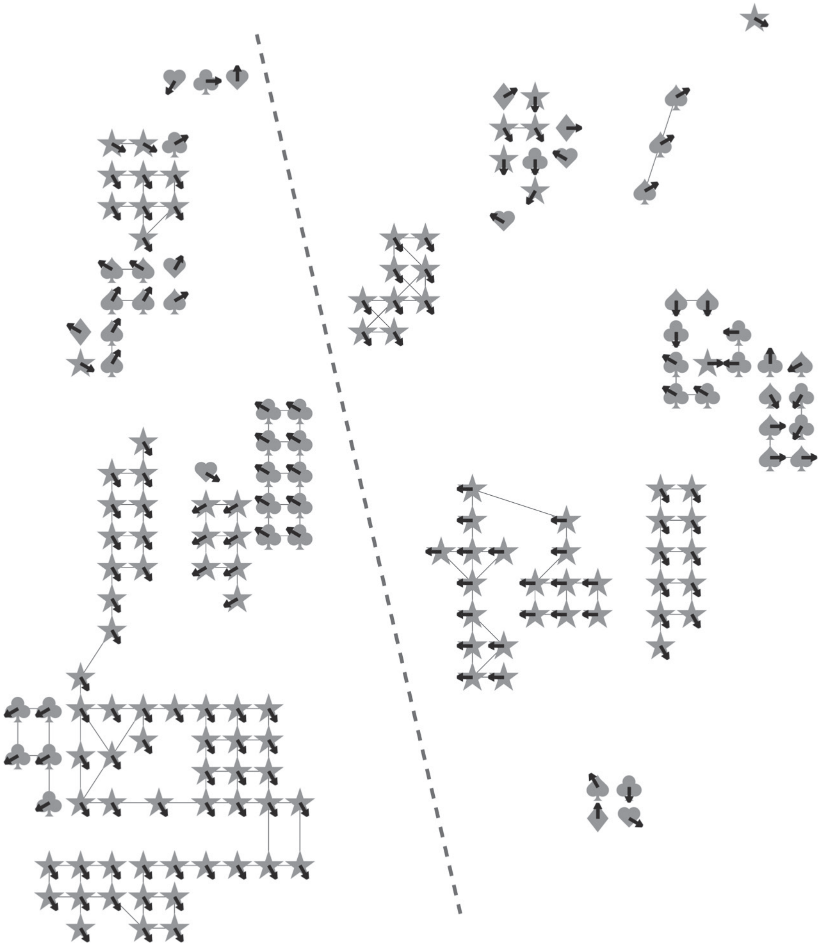

Figure 7.3. State after fifty years from the same run of BaliPlus as shown in Figure 7.2. Clusters of identical icons *(rice variety sequence)* and pointer directions *(starting month)* show that the system has evolved to a state in which pest neighbors *(connected by solid gray lines)* have the same planting schedules. See Figure 7.2 and the text for additional details.

planting schedules. Transmission occurs on a network structured by subak pest-neighbor relationships (cf. Alexander 2007; Grim et al. 2015). The model incorporates a kind of transmission bias known as *success bias* (Boyd and Richerson 1985, 2005; Richerson and Boyd 2005): specifically, individuals—subaks in this case—are more likely to copy cultural variants of other individuals that are more successful—that is, that have better harvests. It is also a niche construction model, since it incorporates feedback from the effects of human behavior on the environment (Odling-Smee, Laland, and Feldman 2003).

Struggle for Order

It seems rational, or at least reasonable, for a subak to switch its planting schedule to that of a neighboring subak with better harvests. However, Lansing's interviews and surveys, as well as historical texts, led him to suggest that subaks do not always act as rationally as his model assumed (2006, [1991] 2007). The actual behavior of subaks departs from that assumed by the model because of intra- and intersubak disputes involving power, status, greed, and so on. Lansing also suggested that religious cultural practices among rice farmers tend to suppress these disruptive tendencies toward such disputes. These practices reinforce a systematic identification of aspects of biotic and abiotic elements of the environment, psychological factors, and spiritual entities (C. Geertz 1981; Lansing 2006, [1991] 2007). For example, the Balinese world is full of demon-like entities known as *bhutakala,* which are common sources of disruption and disorder (Lansing 2006, chapters 5, 7). Some of these bhutakala are identical to rats or insects, while others are identical to aspects of the human psyche that may cause disruptive or otherwise undesirable behavior. People must work constantly to counteract the effects of bhutakala and to restore order and beauty when bhutakala succeed. This effort is simultaneously spiritual and practical, involving rituals and offerings at a hierarchical system of temples, and works to maintain harmonious relations within the democratic councils in villages and subaks that make decisions affecting water and crop management. What we call the religious aspects of Balinese culture are not just a set of policies overlaid on practical matters of water, rice, and pests but a reflection of a conception of nature as an aspect of a pervasively spiritual world. (Nevertheless, investigating cultural change requires distinguishing aspects of culture that may be inseparable from the point of view of members of the society, so I will continue to use *religion* and *religious* to refer to certain cultural patterns that seem, in the abstract, to be very distant from practical matters such as rice growth and pests.)

It may be that the relations of coherence between cultural patterns involved in the subak system include emotional and aesthetic patterns as well as conceptual and social patterns (cf. the above quotation from Geertz). The association of beauty with order is part of what gives maintenance and restoration efforts a subtle emotional dimension:

> The elaborate rituals of the water temples convey a powerful message: that when individuals and subaks succeed in mastering themselves, the world (or at least the microcosm controlled by the subak) becomes more orderly. The flooded terraces resemble sparkling jewels, there are no plagues of pests, and the social life of families and communities is harmonious. On the other hand, when Reason gives way to destructive emotions, the effects are soon seen in quarreling families, disorderly fields, sickness, poverty, and pests. (Lansing 2006, 196)

These remarks suggest that the factors contributing to maintaining the orderly coordination of water management include feelings about the aesthetics of the physical systems, such as rice fields, as well as both personal and social characteristics. Moreover, descriptions of some Balinese ritual performances associated with the subak system (Eiseman Jr. 1989; C. Geertz 1981; H. Geertz 2004) suggest that such rituals might contribute to the cultivation of states of mind that reduce disruption. Eiseman mentions the need to have “a mind uncluttered with confusing or impure thoughts” (Eiseman Jr. 1989, 52) when making holy water, which plays a significant role in rituals associated with the subak system (C. Geertz 1981; Lansing 2006, [1991] 2007). If rituals associated with the subak system generally encourage similarly calm mental states, this might reduce tendencies toward disruptive states of mind.

Hypotheses about the Spread of Balinese Religion

Lansing (2006, [1991] 2007; Lansing and Fox 2011) argued that religious patterns in the rice-growing region differ from earlier royal/Brahmanic religious patterns (cf. C. Geertz 1981) and even earlier Javanese religious patterns, despite many similarities.[14] It is not clear to what extent the dimensions of the rice growers’ subak system mentioned above derive from earlier sources. However, the royal system gives the king a central role in a heroic struggle to maintain spiritual purity against the forces of disorder. These will ultimately prevail, ending in the destruction of the kingdom and perhaps the world itself. By contrast, in the rice growers’ religious system, every person must struggle, repeatedly, both individually and collectively, to restore social and physical order when disorder rears its head. This seems to be a change toward a system that is better for maintaining a harmonious social and agricultural system.

How does a religious system come about that seems, in some respects, as if it were tailored to the maintenance and management of the rice-growing system? Just as we cannot assume that all of an organism's traits are adaptive (Gould and Lewontin 1979), we cannot assume, as mid-twentieth-century social functionalists did, that societies must involve mutually supportive components (Kincaid 2007). The apparent harmony of some of the rice growers' religious patterns with their crop and water management methods needs a causal explanation. The fact that the values and practices of the subak system are similar to, but different from, those of earlier Balinese religious systems and their Javanese (and ultimately, Indian) predecessors suggests that the subak system arose as a modification of those systems. But why would that happen in such a way as to produce the cross-domain harmony that we see? That question is a central focus of this chapter.

Gervais et al. (2011) are surely right in suggesting that in general, biases on cultural transmission can help to explain some facts about religious cultural patterns. There are also explanations of some cross-culturally common religious patterns, such as Boyer's (2001) argument that concepts of spiritual beings are readily transmitted and retained because they are minimally counterintuitive (a cognitive property that has been shown to make concepts easier to remember). However, neither Gervais et al.'s nor Boyer's suggestions seem, by themselves, to be able to explain the way that Balinese religious patterns cohere with cultural patterns in other domains.

Elite Propaganda

One possible explanation of Balinese religious patterns among rice growers could be modeled on Schulte Nordholt's hypothesis about the water coordination system: perhaps a central royal authority constructed the rice growers' religious system and imposed it on them, even though it differed from the royal religious system. That elites may have done this in some societies seems plausible, but it would likely require a systematic propaganda campaign. I am not aware of any evidence that makes this hypothesis plausible for the present case.

Attractive Coherence

Lansing (2006, [1991] 2007) traced historical developments in Balinese religion and its predecessors but did not offer any particular hypotheses about why the rice growers' religious system came to be as it is. However, Lansing and Fox (2011, 933) suggested that the development of the complex Balinese calendar system, which plays an important role in the coordination of planting schedules, "contributed to a mental and physical landscape of pleasing harmonies and perceptible coherence." In context, I read this as a proposal that some religious patterns gradually changed *because* the newer variations helped people in the rice-growing regions feel more comfortable with their world, giving what happened in their lives a deeper explanation and meaning. This proposal implicitly involves a loosely specified psychological hypothesis that people prefer to adopt beliefs and practices that facilitate ways of thinking that are emotionally appealing. Earlier, I mentioned Lansing's (2006) suggestion that the Balinese see a well-functioning rice-growing system as harmonious and beautiful. If Lansing and Fox are right about the Balinese calendar, a similar proposal could be made about other aspects of Balinese religious ideas and practices: beliefs and practices change over time because some combinations of cultural variants feel more beautiful and harmonious together.

This proposal could be made more specific in two general ways:

1. Consciously or not, individuals gradually adjust their cultural patterns to make them more emotionally appealing.
2. When variations in cultural patterns are generated for whatever reason, those that are emotionally appealing are more likely to be copied or to be retained once copied.

The first of these provides a purely psychological explanation that could apply to a change within a single individual, without regard to interactions with others. The second hypothesis, on the other hand, postulates no internal transformations of religious patterns; it only concerns biases on what is transmitted or retained. These hypotheses are not mutually exclusive, however. Also note that if only the first hypothesis were correct, cultural transmission could still play a role in the spread of emotionally appealing patterns, but this need not involve biases toward adopting more appealing cultural patterns, as the second hypothesis requires. Other biases, toward patterns that are commonplace or that are held by high-status individuals, for example, might still play a role. The kind of individual adjustment postulated by the first hypothesis could also play a substantial role in cultural transmission in another way. Sperber and his colleagues (Claidière, Scott-Phillips, and Sperber 2014; Claidière and Sperber 2007; Sperber 1996) have argued that the spread of cultural patterns has more to do with ways in which what is learned is transformed by internal psychological processes. When a cultural pattern is transmitted, it may be *transformed* into something that is more emotionally appealing. I include this as one possible consequence of the first hypothesis.

Lansing and Fox seem to reject the second hypothesis as an explanation of the development of the Balinese calendar; they say that the development of the calendar "is not well captured by a Darwinian perspective" on cultural transmission (Lansing and Fox 2011, 933). However, this seems unwarranted. If pleasing harmonies are appealing to people, why could that not generate biases toward copying some beliefs and practices rather than others?

Applied to religious patterns, the first hypothesis that certain patterns are more likely to be adopted because they feel good looks like ones that Boyer (2001, chapter 1) has critiqued. However, Boyer's argument was that the emotional appeal of some forms of religion cannot answer the question "Why is there religion?" Here the question is, rather, "Why did certain religious patterns change into particular other patterns?" Moreover, the first hypothesis fits loosely with research on cognitive dissonance (e.g., Izuma et al. 2010), according to which people sometimes modify their beliefs to avoid distressing thoughts. There is also research suggests that people have a slight preference for accepting or constructing analogies to what they already believe (Gentner, Holyoak, and Kokinov 2001; Holyoak and Thagard 1995; Thibodeau and Boroditsky 2013). (Note that most accounts of analogy processing treat analogies as involving higher-order coherence relations—a kind of quasi-isomorphism—between sets of beliefs.)

It is worth mentioning here a variation of the second hypothesis that does not depend on emotional effects. There is evidence suggesting that certain kinds of coherence between cultural variants make them easier to retain once learned from other individuals (Bransford and National Research Council 2000; Kline 2015; Mesoudi and Whiten 2004; cf. Caporael, Griesemer, and Wimsatt 2014; Wimsatt and Griesemer 2007). For example, in Upal's (2011) experiments, stories in which all elements are easy to make sense of together were more easily remembered. Thus, as suggested above, it could turn out that religious patterns that fit with what is believed about people and pests and rice paddies are simply more likely to be retained and hence passed on than alternatives, regardless of emotional appeal.

Group Selection

Wilson (2002), commenting on Lansing ([1991] 2007), seemed to suggest that religious dimensions of the subak system evolved by a selection process of some kind, but he did not explain what sort. Wilson's book focuses mostly on forms of group selection, however. Was there competition between subaks, with successful subaks creating new ones? Lansing and colleagues (2009) argued that in some parts of Bali, there is evidence that the subak system spread as some individuals left old subaks and originated new subaks downstream. In the Petanu River watershed, Lansing et al. (2009) argued that this subak "budding" hypothesis is supported by genetic data. This is consistent with a group selectional explanation of change in religious patterns: It may have been that there were chance variations that arose from earlier religious patterns and that some of these variations turned out to help rice farming and water management. Those subaks with the beneficial variants had more food, on average, and as a result their populations increased more rapidly than those of other subaks. Eventually, some members of the high-growth subaks left to form new subaks. This is a form of what Boyd and Richerson call *cultural group selection* (Bell, Richerson, and McElreath 2009; Richerson and Boyd 2005; Soltis, Richerson, and Boyd 1995), whereby some groups grow and create new groups more rapidly than others because of cultural differences between groups.

Despite the evidence for a budding process in the Petanu watershed, Lansing et al. (2009) found no genetic evidence for a similar process in the Sungi River watershed. It is possible that a budding process occurred there at such an early date that migration and intermarriage between subaks, or other factors, have erased genetic evidence of the budding process. Studies of this area were in fact the basis of Schulte Nordholt's ([1996] 2010, 2011) arguments that the water coordination system originated in central planning by representatives of the king. It may be that in some parts of Bali, such as the Petanu watershed, cultural group selection explains the spread of religious patterns that support the water coordination system but that in others, such as the Sungi watershed, a different explanation would be needed.[15]

My Lansing-style budding process explanation of religious change is somewhat similar to an explanation by Norenzayan (2013) and his collaborators (Norenzayan et al. 2016) of the spread of religions that postulate one or more "Big Gods"—all-powerful, omniscient, moralizing, supernatural beings. These researchers argue that Big Gods religions have spread through cultural group selection and success-biased transmission (see below) because the religions promote within-group cooperation. Balinese gods and spiritual beings share some of the qualities of Big Gods, and the subak-local religion can be viewed as a borderline case of what Norenzayan et al. (2016) describe. However, the cultural variants that support rice farming go well beyond the general Big Gods pattern—for example, identifying rats with disruptive spiritual forces (Lansing 2006, chapter 7). Norenzayan et al.'s (2016) proposals can at best provide a partial explanation of the spread of subak-local Balinese religious patterns.

Success-Biased Transmission

The subak religious system may have spread through imitation rather than cultural group selection. If religious patterns prevalent in some subaks resulted in greater food production, people in other subaks may have been more likely to copy these patterns. This is what Richerson and Boyd (2005) call cultural transmission with success bias, a form of model-based bias (since it depends on properties of the individual copied, i.e., the "model"). It is not necessary that members of the society have a clear understanding of the mechanisms by which religious patterns result in better harvests in order for the patterns to be preferentially copied.

The simulation model that I will describe below is designed to show that a success-biased transmission hypothesis is plausible given a Lansing-style emergence model of water coordination. More specifically, my version of this hypothesis is the following:

1. Initially, it was fairly common for disruptive individuals to cause subaks to choose a planting schedule other than one that was most successful in neighboring subaks. Rice-growing peasants used religious patterns that did not mitigate this effect particularly well. Religious patterns at that point may have been closely analogous to Brahmanic patterns and/or may have reflected older Javanese or native Balinese religious patterns.
2. New ideas involving religious patterns similar to those described above developed in one or more individuals—somewhat randomly, though probably partly due to analogies with existing religious patterns and possibly also partly due to analogies with existing practices directly related to water management.[16] A Lansing/Fox style cognitive process favoring emotionally appealing cultural patterns might have played a role in generating new patterns too.
3. Some individuals in some subaks adopted these initially rare concepts, beliefs, and practices, perhaps solely due to chance effects, partly because people are somewhat drawn to analogies of sets of preexisting beliefs (Dehghani et al. 2009; Hofstadter and Sander 2013; Holyoak and

Thagard 1995; Thagard 2000, 2012; Thibodeau and Boroditsky 2011, 2013), or because of other appealing properties of the new patterns.

4. At some point, when *most* members of some local group of subaks had adopted religious patterns like those described above, the result was that people in those subaks had better harvests, on average, because these patterns help to suppress attitudes or behaviors that interfere with the functioning of the water/pest coordination system. (Among other things, the religious patterns might have involved analogies or metaphors that help motivate ways of thinking and behaving that help harvests. For example, an analogy between rats and demons helps to think of rats as agents of disorder. If analogies turn into identifications—rats are themselves demons—then that strengthens the effects of religious variants, since practical matters are then identical to spiritual matters.)
5. Success-biased transmission between local groups then resulted in other subaks adopting the same religious patterns. The idea is that individuals in one subak noticed that another subak had better harvests and guessed that part of the reason was because their religious beliefs and practices were correct or beneficial due to spiritually mediated effects. (This idea is analogous to one dimension of Norenzayan's [2013; Norenzayan et al. 2016] proposal that "Big Gods" religions such as the Abrahamic religions spread because of features that facilitated within-group cooperation. Those adopting a religion will often attribute the success of those they are copying to spiritually mediated help, even if the same success can be explained by the religion's effects on practical behavior. In the Balinese case, too, it seems that the benefits of certain religious patterns can be explained without recourse to spiritual hypotheses.)

An Extended Lansing Kremer–Style Model

In order to investigate the preceding hypothesis, I developed an extended Lansing-Kremer model (BaliPlus). The results show that under some conditions, processes like the one just described can indeed lead to the spread of new religious patterns because of their effects on harvests. The model represents the cultural forces and patterns discussed in earlier sections with a considerable degree of abstraction. The preceding discussion is valuable, I feel, because it allows an understanding of what kind of real-world phenomena motivate the model and what it is that is being abstracted away.

Overview

In order to explain how elements of the hypothesis described above are represented in the model, I will begin with a general description of the BaliPlus model and then describe how the preceding hypothesis can be tested using this model.

GENERAL CHARACTERISTICS OF THE MODEL

To model success-biased transmission of religious variants in an abstract fashion, I began with Janssen's (2012) version of Lansing and Kremer's model and added additional variables and functions:

- The model has a global "capriciousness" variable to represent the overall effects of greed, jealousy, and so forth on individual subaks' planting-schedule choices. More specifically, I treat capriciousness as a probability of an individual subak randomly choosing a different planting schedule than that of the neighboring subak that has the best harvest.[17]
- Each subak has a variable representing its "religious" cultural variant, represented as a number between 0 and 1. Religious variants near 1, which represent a degree of closeness to recent Balinese patterns, tend to suppress the effects of capriciousness. I investigated several mappings of values of this variable to effects on capriciousness, including a linear relationship and three functions that gave greater weight to higher-valued religious variants.
- Once per year, subaks copy religious variants from other subaks that have better harvests. This copying process is not perfect: The new religious value received by a subak is roughly normally distributed around the transmitting subak's value. (It would be precisely normally distributed, except that I restrict religious values to the interval [0,1]. If the sum of the transmitter's religious value and a normally distributed random number with mean 0 lies outside this interval, the subak is assigned, as its religious variant, the nearest extreme value.)
- Subaks may copy religious variants from either pest neighbors or from members of a randomly selected set of subaks from the global population. The rationale for this rule is that there is no good reason to restrict religious copying to pest neighbors, but pest neighbors are near each other, so copying from them would probably be more likely. I investigated various ways to implement this idea.

In summary, subaks copy both planting schedules and religious variants from subaks that have more successful harvests, but they copy religious variants from a larger set of subaks, and religious values influence the tendency of subaks to choose merely random planting schedules instead of the best pest neighbor's schedule.

The model operates as follows:

- Subaks are initially assigned randomly chosen planting schedules and uniformly distributed random religious variants between 0 and 1.
- After a six thousand-month = five hundred-year "burn-in" period,
- the model runs for twenty-four thousand months = two thousand years.[18]

Since the model is stochastic, we ran one hundred simulation runs for each set of fourteen parameter variants described below,[19] under five different pest and rainfall parameter combinations—a total of seven thousand simulation runs. An appendix summarizes all parameter settings.

OVERVIEW OF HYPOTHESES TESTED

Earlier, I described a hypothesis about how success-biased transmission could lead to the spread of religious patterns that facilitate the coordination of water and crop management. How can we translate this hypothesis about cultural processes in the world into the framework of the BaliPlus model sketched above? Two things need to be shown.

1. Capriciousness should reduce harvests: A background assumption of the success-biased transmission hypothesis was that some members of the community engage in disruptive behaviors that interfere with the coordination of planting and water use, and this results in a reduction of harvests relative to what would happen otherwise.[20] In BaliPlus, random planting schedule choices controlled by the capriciousness variable represent this kind of disruption. We need to make sure that capriciousness in BaliPlus does in fact lead to a decrease in harvest success compared to the original Lansing-Kremer model. This must be done without allowing religious patterns to suppress effects of capriciousness so that we can understand the impact of religious effects later.
2. After adding the transmission of religious variants that are capable of suppressing capricious effects:

(a) The population average harvest level should be higher with religious transmission than with capriciousness and no effects of religious variants because
(b) capriciousness-suppressing religious variants—those with values near 1—should become widespread within the population (and thus suppress the effects of capriciousness).

THE PROBLEM WITH GLOBAL TRANSMISSION

I initially believed that part 2 of the preceding hypothesis would be satisfied when

- each subak chose another subak from which to copy religious values by examining the harvests of all 172 subaks in the population and then copying from the subak with the best harvest.

Preliminary experiments suggested that this would almost never lead to the spread of religious variants near 1. When subaks use success-biased copying from the entire population, all subaks quickly converge to an apparently randomly chosen, narrow range of religious variants. The narrow cluster of religious values of the population then shifts to higher or lower values in what looks much like a random walk.

The explanation for this behavior is this: In order for harvest success bias to lead to the spread of high religious values, there has to be a positive correlation of harvest success and high-value religious variants. The model begins without any such correlation. All subaks then copy the religious variant of the one subak (or few subaks) that happens to have the highest harvest value. This value is roughly as likely to lie in any one region of [0,1] as in any other. All subaks then have approximately the same religious variant, and there is no variation in religious variants on which success bias can operate. The correlation between religious values and harvest success remains low, not because both values are randomly distributed but because of the lack of variation in religious variants. Success-biased copying from the global population never gets off the ground because there is no variation in religious behavioral patterns. To summarize:

- At the beginning of the simulation, when subaks first compare harvests across the entire population, there will be no association between religious values and harvest success.

- Since all subaks copy the best harvests, variation in religious variants disappears.
- After that, narrowly clustered religious variants random-walk (roughly speaking) due to transmission noise.

So religious variants with values near 1—those that suppress capriciousness—are unlikely to be spread due to success bias when success-biased copying considers the entire population. Thus, in the simulations described below, members of various smaller, partially random subsets of the global population serve as possible sources of religious variants.

Details of Simulations

CULTURAL TRANSMISSION NETWORK STRUCTURE

Subaks examine possible sources for religious variants according to the following rules:

1. Each subak always considers imitating the religious variants of its pest neighbors.
2. Each subak also considers imitating the religious variants of a Poisson-distributed number of subaks from the entire population, with the mean number of subaks equal to one of the following three values: .025, 1, 50. This (randomly chosen) number of subaks is then randomly chosen from the other subaks, without replacement. If the number of subaks that results is greater than 171 (the total number of other subaks), all 171 subaks are examined. Note that a pest neighbor can be chosen, in which case the choice of this "additional" subak from the global population has no effect.

CAPRICIOUSNESS AND THE EFFECT OF RELIGIOUS VARIANTS

In simulation runs that include capriciousness, after every subak has acquired a new planting schedule from a pest neighbor or has retained its previous schedule, a probability of acquiring a new randomly chosen planting schedule is calculated. This probability is set to 0.3 if there is no religious transmission. If there is also religious transmission, then the probability of acquiring a random planting schedule is 0.3 times the distance from 1 of the subak's *religious effect* (see below), reduced by a factor of two-thirds.[21] That is, when there is religious transmission, the probability of choosing a new, random planting schedule is:

$$0.3 \times 2/3 \times (1 - \text{religious-effect}) = 0.2 \times (1 - \text{religious-effect})$$

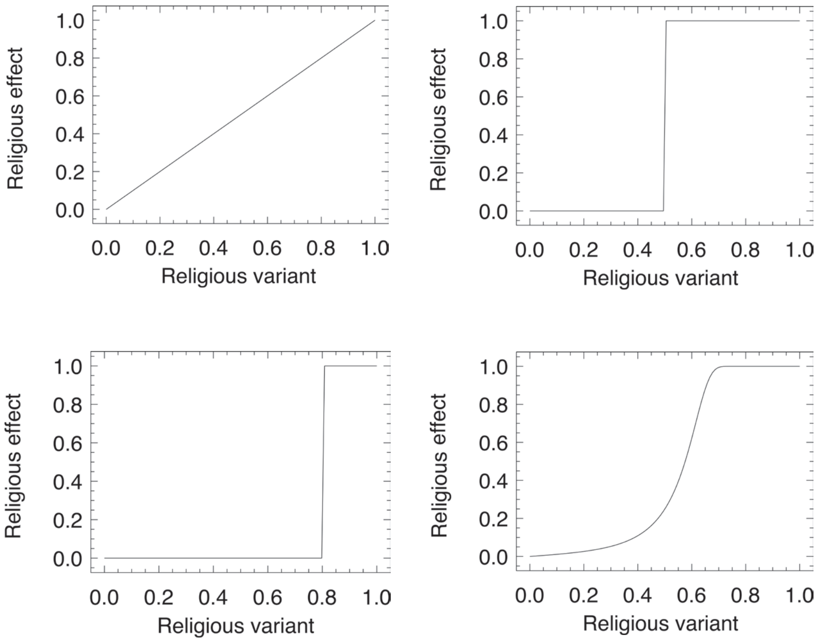

Figure 7.4. Four religious effect curves, each used in a different set of simulation runs.

What is *religious effect*? This number is set as a function of the subak's religious variant. The simplest way to do this would be to set the religious effect for a subak (in a given year) equal to the value of the subak's religious variant. This might not accurately represent what goes on in the world, however. It may be that as one acquires more components of a complex cultural pattern, its cumulative effect increases nonlinearly because of the way that its components reinforce each other. Thus, I ran simulations using four different *religious-effect functions,* each of which maps a subak's religious value in [0,1] to a degree of capriciousness suppression. The first religious-effect function simply treats the value of a religious variant as the strength of the religious effect; the other three produce different kinds of threshold effects, with a sharp increase in the intensity of the religious effect once the religious variant reaches a certain level (Figure 7.4):

1. **Linear:** religious effect = religious variant.
2. **Step at 0.5:** A function that maps religious variants below 0.5 to 0 and religious variants greater than or equal to 0.5 to 1.

3. **Step at 0.8:** A similar step function with a step at 0.8 rather than 0.5.
4. **Sigmoidey:** This is similar to a step function but is designed to allow a gradual increase in the suppression of capriciousness as the value of the religious variant increases. For religious variant *v,* this function is

$$\tanh \frac{v}{e^{2.25}(1-v^2)^{e^{1.7}}}.$$

I chose the form of this "sigmoidey" function partly by trial and error. It is not important that one understand the details of this function; it is simply a function that allows a wide variety of monotonically increasing curves between 0 and 1 to be generated by substituting other numbers for 2.25 and 1.7. I chose this particular curve with parameters 2.25 and 1.7 because it was step-like yet gradual and similar to the two pure step functions.

PESTS AND RAINFALL

Janssen's (2012) NetLogo (Wilensky 1999) version of the Lansing-Kremer model allows rainfall to be set at three levels, *low, middle,* and *high.* There are also variables that control pests' growth rate (with values ranging from 2.0 to 2.4) and the rate of pests' dispersal to pest-neighbor subaks (values ranging from 0.6 to 1.5).[22] We ran fourteen sets of one hundred simulations, each with the following five rainfall and pest parameter combinations:[23]

- High pest, high rain
- High pest, low rain
- Low pest, high rain
- Low pest, low rain
- Middle pest, middle rain

High pest means that pests' growth and dispersal values were set to the highest values allowed by the NetLogo model; *low pest* means that these values were set to the lowest allowed values. *Middle pest* means that the pest growth rate was set to 2.2 and that the pest dispersal rate was set to 1.0. These are the values that Janssen (2007) used as intermediate values for his analysis.[24]

To summarize, for each of the five configurations just mentioned, we ran one hundred simulations in each of the following fourteen conditions (seven thousand simulations in all):

1: The Lansing-Kremer model: no capriciousness, no effects of religious variants.
2: The same model with the addition of the effects of capriciousness but no effects from religious variants.
3-14: Twelve different configurations in which both capriciousness and religious variants have effects. These twelve hundred simulations cover each combination of the three communication network structure parameters and the four religious-effect functions described above.

The first two configurations were intended to test the first hypothesis described in the section titled "Overview of Hypotheses Tested." The other configurations were intended to test the second hypothesis described there.

Results

Since all five pest/rainfall configurations gave qualitatively similar results, it will be easiest to present results only from the fourteen hundred simulations in the high pest, low rain configuration; this is one of the two configurations that produced the least striking confirmation of my main claims.[25] (Plots from the other four pest and rainfall configurations will be available online or by request from the author.)

GENERAL REMARKS

In the pure Lansing–Kremer configuration and in the runs with both capriciousness and the effects of religion, the population average harvest usually settles down to a value around which there are small fluctuations, with occasional long-term shifts, also small. There is a bit more variation in harvest values in the configuration with capriciousness and no religious effects, but these changes usually remain close to a central value. For each combination of conditions, the average harvest value around which there are small fluctuations varies from run to run.

Populations' average religious variants often vary quite a bit over the two thousand years in each simulation run. Close examination of the data makes it clear that even in runs in which the average religious variant has a high value during most timesteps, it sometimes takes a long time to arrive at that value, and in some cases the average subsequently drops down to a much lower value. As the figures below show, meaningful differences between the fourteen parameter settings concern distributions of *average* population-level effects over post-burn-in years in the one hundred runs with the same parameters. It is perhaps realistic that no condition in the model guarantees a particular result, especially in the case of religious variants.

HYPOTHESIS 1: EFFECT OF CAPRICIOUSNESS ALONE ON HARVESTS

Figure 7.5 shows that adding capriciousness to the pure Lansing–Kremer model does indeed reduce harvests, on average (the first hypothesis described in the "Overview of Hypotheses Tested" section). Since in any given year not all subaks have the same harvest, I used a measure of the per-year-population-average harvest *(avgharvestha).* This value fluctuates from year to year in each model run, so I averaged it over two thousand years after the five hundred-year initial settling period. What Figure 7.5 shows, then, is the distributions of the resulting value in one hundred runs without capriciousness and in one hundred runs with capriciousness. Note that although capriciousness reduces harvests on average through reduction in the coordination of planting schedules, the overlap in the two curves in

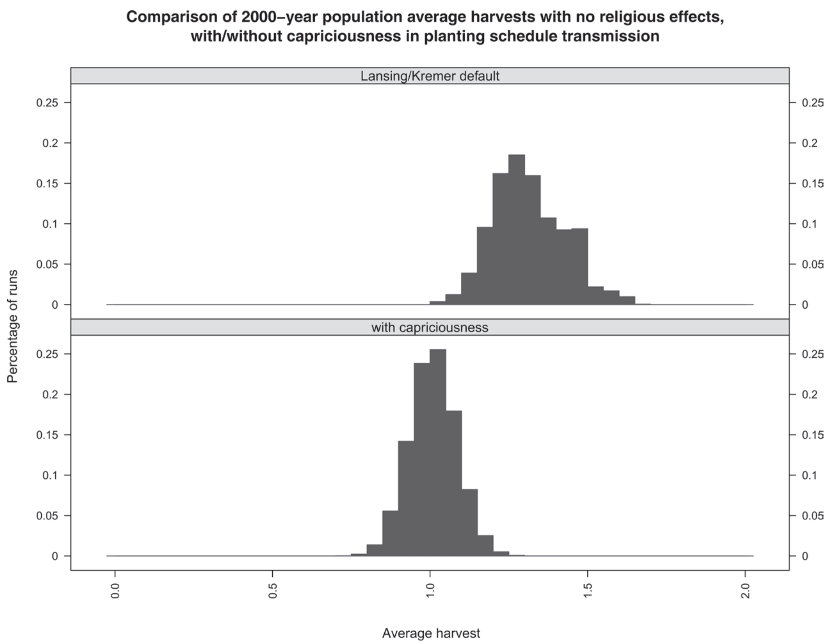

Figure 7.5. One hundred-run distribution of averages over two thousand years and all subaks of the per-year population-level average harvest values *(avgharvestha)* under two conditions. *Horizontal axis:* harvest value. *Vertical:* relative frequency in one hundred runs. *Top:* pure Lansing–Kremer model without added capriciousness. *Bottom:* Lansing–Kremer model with added capriciousness.

Figure 7.5 (between about 1.0 and 1.25) shows some capriciousness runs *(bottom panel)* with better average harvests than in runs under the pure Lansing–Kremer condition *(top panel).* Capriciousness does not guarantee a poorer harvest.

HYPOTHESIS 2A: EFFECT OF RELIGIOUS VARIANTS ON HARVESTS

As noted above, in addition to the two sets of one hundred simulation runs just described, we ran twelve sets of one hundred simulations in which religious variants spread (three transmission schemes) and suppressed the effect of capriciousness on subaks when their religious variants were near 1 (four religious-effect functions). The results varied between the twelve conditions, but in each of the twelve conditions, harvests were better on average than in the pure capriciousness condition. Figure 7.6 shows this. In each of the twelve plots, an outline histogram shows the same one hundred-run distribution of two thousand-year average harvest values with capriciousness

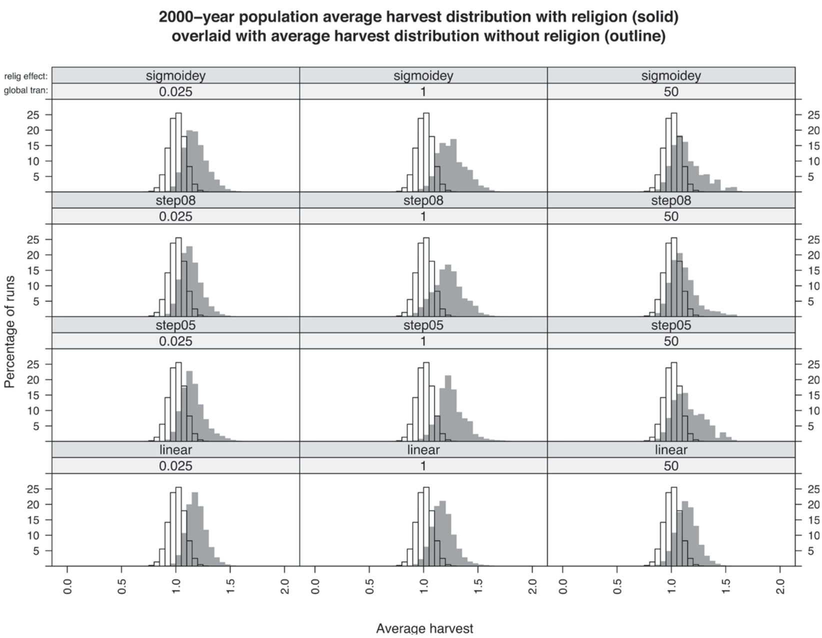

Figure 7.6. One hundred-run distributions of two thousand-year average harvests with capriciousness and spread of religious variants *(solid bars)* under twelve parameter combinations, compared to the same distribution with capriciousness alone *(outline bars). Upper row of labels (sigmoidey, step08, step05, linear):* religious-effect function. *Lower row of labels (0.025, 1, 50):* approximate mean number of subaks from global population examined for religious transmission.

but no suppression by religion (corresponding to the lower plot in Figure 7.5), with a different solid-color plot of average harvests, one for each of the twelve religious-effect conditions. It is worth remarking that though the combination of the effects of religion with capriciousness produces greater harvests on average than with capriciousness alone, the effects of religion do not completely undo the effects of capriciousness. Under most of the parameter combinations, the mean of the religious-effects-plus-capriciousness curve is intermediate between the means for capriciousness alone and for the pure Lansing–Kremer model (not shown in Figure 7.6).

HYPOTHESIS 2B: SPREAD OF RELIGIOUS VARIANTS

Recall that in BaliPlus, in order to determine whether to copy another subak's religious variant, each subak looks at each of its pest neighbors as well as members of a (possibly empty) randomly chosen set of subaks from the entire population. The *size* of this set of randomly chosen subaks is itself random, with three different possible mean *global transmission* values for the probability of sizes. That is, the number of subaks examined is chosen randomly for each subak in each year, but the mean of the random distribution over these numbers is set once for each simulation run. This global transmission mean thus represents an average tendency for communication about religion across the entire population of subaks.

Figure 7.7 shows that capriciousness-suppressing religious values tend to spread when communication between nonneighbors exists but is rare (global transmission mean = 0.025 or 1). The effect is more pronounced with some religious-effect functions *(displayed top to bottom).* By contrast, when the number of nonneighbors considered for comparison is large (global transmission mean = 50), there is no pronounced tendency for religious variants with high values to spread. Informal exploratory simulations using BaliPlus suggest that allowing communication with even higher numbers of subaks would decrease the likelihood of the spread of high-value religious variants further.

Close examination of the ways in which average religious variants change over time shows that even in those conditions that tend to spread high-valued religious variants, the average religious variant sometimes dips down to intermediate or low values for extended periods of time *(not shown).*[26] Some global communication parameter combinations do better at "capturing" high-valued average religious variants for extended periods of time. For example, in the simulation runs in which communication across the entire

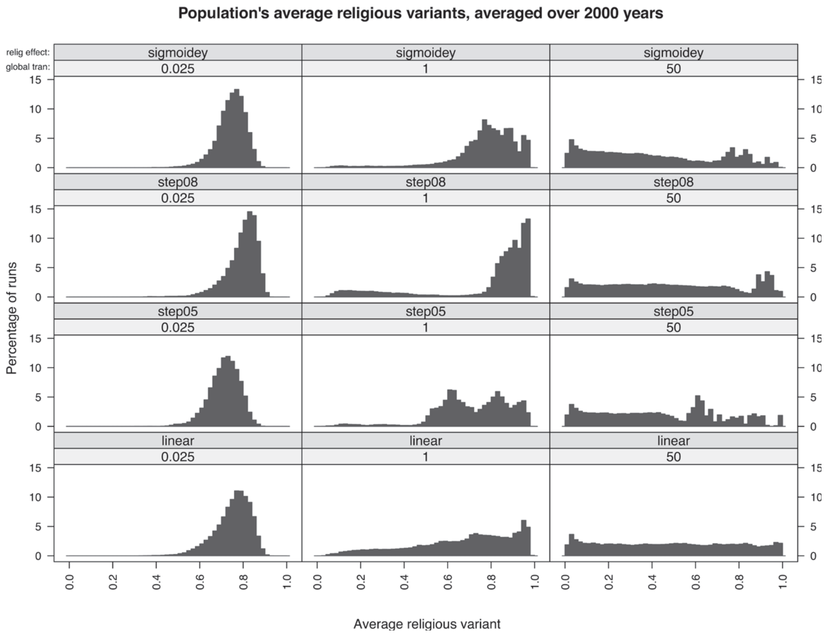

Figure 7.7. One hundred-run distributions of two thousand-year average religious variant values with capriciousness and spread of religious variants under twelve parameter combinations. Upper row of labels (*sigmoidey, step08, step05, linear*): religious-effect function. *Lower row of labels (0.025, 1, 50)*: approximate mean number of subaks from the global population examined for religious transmission.

population is common—summarized in the right column of Figure 7.7—population averages for religious variants usually wander across much of the range of possible values, although religious values spend more time at high values in a few simulation runs. In the other two communication conditions *(left, center columns),* population averages wander until they happen to reach higher values and then stay there—usually. It appears that the manner in which the average religious variant does or does not wander in various situations is what accounts for the distributions represented in the histograms in Figure 7.7.

DISCUSSION

General Remarks

The results described above show that under certain conditions religious patterns can spread because they have, as one of their effects, suppression of behavior that interferes with mechanisms that otherwise produce widely desirable results such as larger harvests. The simulations support a "how-possibly" (Brandon 1990) explanation of the spread of these religious patterns in Bali. Specifically, the model lends support to the hypothesis that religious patterns involved in the Balinese planting/water-coordination system spread through success-biased cultural transmission between members of different subaks, with stronger and more regular influences between neighboring subaks than between more distant subaks. According to this hypothesis, those religious patterns that facilitated the subak-based crop and water management system by suppressing capricious behavior were those that managed to spread after partially random changes allowed some clusters of subaks to develop new, beneficial patterns. People in some subaks decided that others' religious patterns that seemed to lead to better harvests were worth copying. By running the simulations with a variety of parameter combinations, the simulations suggest that religious patterns that reduce capriciousness can spread by this kind of mechanism under a broad range of conditions.

My model illustrates how different domains of a culture can come to exhibit coherence in two senses. First, that religious patterns have beneficial effects on practices that support successful farming is a kind of coherence between religion and farming practices; the simulations show how this kind of coherence might come about. Second, although my model does not represent details of Balinese religious patterns, it is inspired by them and represents them in an abstract way. It can thus be viewed as a model of the spread of these more detailed religious patterns. These patterns seem to allow Balinese people to treat threats to harvest success—such as pests and greed—as threats to a spiritual order that is seen as emotionally and aesthetically attractive. Restoration of order is supposed to be sought both through religious practices implemented by individual farmers—offerings at local shrines, for example—and by religious practices of groups, which in turn are linked to democratic institutions at the levels of villages, subaks, and groups of subaks. Balinese religious patterns in the subak system thus exhibit various detailed coherence relations between religious and pragmatic practices of various kinds. The simulations show how such patterns might have spread.

This project is unusual in trying to explain certain kinds of coherence in a particular culture in terms of a specific mechanism of cultural transmission and in using computer simulations to do so. Explanations of general kinds of cross-cultural change, such as Norenzayan (2013), Norenzayan et al. (2016), or Sanday (1981), can be important, but much of what is interesting about culture is specific to particular societies. Illustrating new strategies for investigating local cultural change, as I do here, is valuable.

Intermittent Copying

In order for the success-biased transmission hypothesis to explain the cultural patterns that are my focus here, it appears to be necessary that subaks' tendencies to copy others' religious patterns involve only intermittent copying from more distant members of the global population. This is because capriciousness-suppressing religious patterns help harvests only when subaks connected by pest-neighbor relations adopt these same cultural patterns, allowing them to come to have the same planting schedules. If the harvests of all or many subaks were examined in order to determine which religious patterns were to be copied, then—assuming religious variation is initially random with respect to harvest success—many subaks would copy the religious patterns of a small number of subaks that happen to have the best harvests. This results in very little religious variation across the population, and without sufficient variation, it is unlikely that any cluster of subaks would come to have religious patterns that suppress capriciousness. Yet without concentration in clusters, capriciousness-suppressing religious patterns would have no particular advantage, so other subaks would not preferentially copy them. Thus, capriciousness-suppressing patterns would not spread.

On the other hand, if—as in some simulations described above—subaks always examine neighbors' harvests but occasionally also examine more distant subaks in order to decide whether to copy religious patterns, it is possible—again, by chance—for the members of one local cluster of subaks to adopt capriciousness-suppressing religious patterns from each other. This cluster will be likely to maintain its religious patterns over time; the members' harvests will usually be better than those of other subaks, so there will be no reason for them to copy religious patterns from outside the cluster. Then, when subaks from elsewhere eventually examine the harvests of members of this cluster, they will see that their harvests are better and will copy their religious patterns. At some point this process will result in a second cluster in which capriciousness-suppressing religious patterns are the norm, increasing the speed of the spread of these patterns. Over time, this process will lead to capriciousness-suppressing religious patterns spreading throughout the population. Subsequently, random factors can occasionally result in periods of time in which capriciousness-suppressing patterns are not widespread, but those periods will usually be relatively short-lived.

The way in which this model explains religious patterns raises a question for empirical research: Is it likely that such intermittent communication did occur in Bali? There are a variety of ways in which it might have occurred. First, note that subaks are composed of villages, which in turn are composed of many individuals. Second, note that real Balinese religious patterns are enormously more complex than the simple numeric values that BaliPlus uses to summarize variation. These two points allow for a variety of network effects that could produce the kind of intermittent influence modeled in BaliPlus:

1. It may simply be that contact between members of different subaks is itself intermittent. Various factors might interact here: distance, trade, kinship, friendship, and so on.
2. Within any given social group, those who communicate more often may be more likely to influence common cultural patterns, thus making it more difficult for cultural patterns held by others to spread within that group (cf. Abrams 2014; Alexander 2007; Caporael 2014; Morris 2000; Young 1998; chapters 1 and 12 of this book). The idea is that communication between people who are all in the same subak can reinforce others' cultural patterns. This could make it difficult for other cultural patterns from distant subaks to be taken seriously, even if communication with those subaks was not uncommon, and the distant subaks' religious practices were well known and appealing due to success bias. Other sorts of social identity might constrain communication as well (see chapter 12).
3. Some individuals within a group may have more influence than others due to having power of various sorts or being successful in ways not reflected in a simple model—perhaps due to likeability, charisma, or a reputation for wisdom or knowledge (cf. Durham 1991; Henrich and Broesch 2011; Richerson and Boyd 2005; Smaldino 2014). If particular individuals of this kind are not receptive to new cultural patterns, that fact can make it less likely that new patterns will spread in the social group.
4. As discussed in the first section of this chapter, some combinations of religious beliefs or practices may be infelicitous with others, create cognitive dissonance together, or even be logically contradictory, while other combinations may be more acceptable to many individuals, given

other prevalent cultural patterns. These relationships between cultural patterns generate a kind of interpersonal network structure, in that some cultural variants strengthen or resist influence from others: even if each member of subak S_1 is bombarded by influences from members of all other subaks S_k, it may be that because of relative incompatibility between cultural variants, certain religious patterns new to S_1 have a low probability of influencing anyone in S_1 and do so only occasionally (cf. Abrams 2013; Atran and Medin 2008; Axelrod 1997; Hegselmann and Krause 2002; Mueller, Simpkins, and Rasmussen 2010; Zollman 2013). One way in which this kind of phenomenon can occur is when some cultural variants scaffold or otherwise facilitate the learning of others; if an individual has not yet adopted the former patterns, the adoption of new religious beliefs or practices may be difficult or unlikely (cf. Abrams 2015a, 2015b; Kline 2015; B. H. Wimsatt 2014; W. C. Wimsatt 2014; Wimsatt and Griesemer 2007; chapter 1 of this book). However, the ways in which adopting cultural variants facilitate or hinder the adoption of others need not always exhibit the kind of typical linear sequence suggested by the concept of scaffolding or the analogy with biological development, as discussed by Wimsatt and Griesemer (2007; W. C. Wimsatt 2014; Wimsatt, chapter 1 of this volume). In Abrams (2015b) I suggested that all such cases could be conceptualized in terms of *transition probability interaction:* that probabilities of adoption of some cultural variants are conditional on what other cultural variants have been adopted (cf. Abrams 2015a).

What Is It a Model Of?

Some aspects of the BaliPlus model are clearly unrealistic. The original Lansing–Kremer model represented months and years in timesteps in order to organize modeled water flow, pest behavior, and planting schedules. It also made the simplifying assumption that subaks only consider changing planting schedules at the end of each year. In BaliPlus, subaks consider copying religious variants on the same annual schedule, but I have no empirical justification for the assumption that religious transmission should happen on the same timescale as agricultural decisions. I chose various other parameters (see the appendix) somewhat arbitrarily. For example, there is no strong reason for choosing 0.3 as the base probability of randomly choosing a planting schedule. However, the point of the model is to explore the possibility that certain kinds of religious patterns might spread, probabilistically, under the influence of factors specified by the parameters described above (and in an appendix). The rationale for choosing basic parameters such as this one is that the parameters allowed the possibility of generating the kinds of effects I was interested in investigating. Still, because of these relatively arbitrary assumptions, two thousand "years" of *communication as represented in the model* is not necessarily realistic, despite the fact that two thousand years is a period over which, realistically, there might have been rice farming in Bali (Lansing et al. 2009; see note 18). Nevertheless, the point of the BaliPlus model is to show how a particular *kind* of process might explain the spread of religious patterns conducive to planting and water management. We can view these simulations as illustrating certain kinds of processes by which cultural patterns can spread because of the very indirect influence on outcomes that are clearly valued (rice production, in this case).

There is, moreover, a more general point that has emerged from the simulations reported above. By embedding the transmission of religious patterns capable of influencing decisions about planting into simulations that had already modeled interactions involving rice growing, water flow, and the effects of pests, we learn the following: At least in cases sufficiently analogous to those modeled here, the practical effects of religious patterns can explain their spread *under the condition that this transmission is usually local and intermittently global.* Of course, what counts as sufficiently analogous to the Balinese case as modeled here is not clear. (One reason for this has to do with the complexity of the ecological processes modeled in Lansing and Kremer's and Janssen's simulations and in BaliPlus.)

Other Hypotheses

Even if success-biased transmission does explain the spread of certain Balinese religious patterns, that does not rule out some of the other explanations in the section on hypotheses about the spread of Balinese religion. Humans are complex, so there may be complementary explanations of cultural change that depend on different, potentially interacting processes. As noted above, Wilson (2002) seemed to suggest that religious patterns among Balinese rice farmers could be explained by group selection. While Lansing et al.'s (2009) "budding" model of the spread of the subak system fits Wilson's group selection hypothesis, it is not entirely clear whether this model fits all regions of Bali in which the subak system is common. Group selection may be part of the explanation for Balinese religious patterns, as might Lansing and Fox's (2011) hypothesis that certain cultural patterns arose in individuals because these patterns were psychologically more satisfying. I suggested that such psychological effects might also bias cultural transmission to favor the transmission and the retention of certain patterns. Perhaps religious patterns in Balinese rice-growing regions arose and spread due to a combination of individual psychological transformations, biases due to psychological attractiveness and harvest success associated with certain religious patterns, and group selection resulting from better harvests.

Moderate-Complexity Model Benefits

I developed another set of simulations (Intermittran, https://github.com/mars0i/intermittran) that were inspired by, but not directly based on, Lansing and Kremer's model. These simulations are not my focus here, so I will not go into detail about them, but it is worth mentioning some differences with BaliPlus. In Intermittran, I simplified BaliPlus's complex ecological feedback effects on harvest success to a simple function of nearby subaks' religious values combined with random noise. With this model, it is challenging, though not impossible, to produce results that are qualitatively similar to those in BaliPlus. The problem is that Intermittran makes it too easy to cause high-value religious variants to spread to all subaks and too easy to subsequently maintain a high average value. By contrast, in BaliPlus, even in those runs with parameter values that tend to make a population spend large amounts of time with high average religious variant values (Figure 7.7, *left and middle columns*), quite a few runs spend significant amounts of time with lower average religious variant levels—even after many years at high values *(not shown)*.[27] I was able to produce qualitatively similar behavior in Intermittran only through somewhat careful tuning of the random distribution that affects harvest success.[28] Because of this, I am skeptical that the kind of noisiness produced by the real-world ecological relationships modeled in BaliPlus can easily be approximated by reducing them to random distributions of the kind typically chosen by modelers.[29]

There is a common view (e.g., Epstein 2006) that it is best if agent-based simulations are *simple-agent models* (Abrams 2013)—that is, models in which the behaviors of agents are governed by a few simple rules. Otherwise, given a large number of interacting agents, it can be difficult to understand what is significant in the production of the model's behavior. The simple-agent strategy is a good heuristic, but it is not clear that the insights gotten from BaliPlus could have been gotten using only simple-agent models such as Intermittran. In Abrams (2013) I argued that there is value in developing agent-based models that involve somewhat more complex processes. The fact that it is difficult for Intermittran, a simple-agent model, to reproduce behavior like that in BaliPlus—apparently because of the way in which BaliPlus models complex ecological processes—provides some additional support for this point.

RELIGION IS an important topic because of its important role as a distinct cultural domain in modern industrialized societies. This chapter was not motivated by an interest in religion, however. My use of *religion* and *religious* to describe the cultural patterns that were the focus here merely provided a convenient shorthand for certain patterns within the Balinese rice-growers' culture. Since for the rice growers the physical world is spiritual and what is spiritual is continuous with the physical world, Balinese culture is one of those in which it is misleading to conceptualize religion as a distinct cultural domain (e.g., Descola 2005; C. Geertz 1973b; H. Geertz 2004; González 2001; Lansing 2006; Lienhardt 1961; Tilley 2000).[30] This is not to say that "religious" change must also involve changing all dimensions of culture (farming, eating, hunting, dress, etc.). Otherwise, all cultural change would require radical cultural saltations. I think that the evidence from historical ethnographic research such as Lansing's suggests otherwise.

What I find fascinating is that cultural patterns I have labeled *religious* seem, at first glance, to have no direct impact on practical needs, such as the provision of food or shelter. For example, the Balinese may have thought that religious practices intended to mitigate the effects of demons are relevant to farming because rats are in fact demons, but an outsider may find it mysterious why those practices should improve rice growing. By contrast, some cultural patterns can readily be understood as direct responses to subsistence needs, given environmental conditions and prior cultural traditions. The fact that Balinese farmers grow rice in paddies is probably a response to ecological facts about Bali and how rice can profitably be grown, in combination with the existence of rice growing in the societies from which theirs descended.

Part of what sometimes makes those cultural patterns classified as religious puzzling is that they seem distant from such pragmatic concerns, providing little obvious material benefit and costing a great deal. When religious patterns seem to cohere, in some clear sense, with patterns in other more pragmatic cultural domains, there is an additional puzzle: What explains the relationship between patterns in a pragmatic domain and those in one that could have been, one would think, completely independent of it?

What I have illustrated here is one strategy for understanding how such patterns could spread and come to "fit" with those that have more immediate practical consequences: cultural patterns without direct pragmatic consequences can have the effect of adjusting behaviors in subtle or complex ways so that the behaviors end up having improved practical consequences, perhaps for reasons that are not apparent to the participants. This can lead to success-biased preferences for copying those cultural patterns and thus spreading the "impractical" patterns, creating and maintaining a harmony between apparently disparate cultural domains.[31]

APPENDIX: SIMULATION PARAMETERS

NetLogo 5.2.1

Source file: src/LKJplus/BaliPlus.nlogo

(Versions of November 2015; some with trivial modifications from January and February 2016)

burn-in-months = 6,000 (500 years)

months per run: 30,000 (2,000 years plus 500 years burn-in)

Pest and rainfall configurations:

	pestgrowth-rate	*pestdispersal-rate*	*rainfall-scenario*
high/high	2.4	1.5	"high"
high/low	2.4	1.5	"low"
low/high	2.0	0.6	"high"
low/low	2.0	0.6	"low"
mid/mid	2.2	1.0	"middle"

Notes: The high/low configuration is the one from which data were reported in the text.

relig-tran-stddev = 0.02
relig-influence = 1.5
Used only the five crop plans that include only traditional rice varieties (1 and 2)
(I.e., rice variety 3 was not used in any model.)
For runs with capriciousness, *ignore-neighbors-prob* = 0.3
Religious effect functions:

- step at 0.5
- step at 0.8
- linear (i.e., suppression effect = value of religious cultural variant)

- "sigmoidey" with *relig-effect-center* = 2.25; *relig-effect-endpt* = 1.7 (see text for function definition)

Poisson means for the addition of subaks from the global population to those neighboring subaks who are candidates for transmission: *subaks-mean-global* = 0.025, 1, 50

NOTES

1. See also arguments, such as Page's (2007), that drawing upon diverse cultural backgrounds or ways of thinking can be valuable, for example, in problem solving.

2. This is not the place to discuss views that hypostatize culture as something that lies beyond the mental states, behaviors, and artifacts of a society (Clark 1999; Risjord 2014).

3. Kuhn (1996) describes similar patterns in scientific communities that share a paradigm; these might be called scientific cultures. Much of the evidence for cultural coherence comes from qualitative research, but Dressler, Balieiro, and dos Santos (2017) provide statistical evidence for coherence relations between different domains of life among urban Brazilians.

4. For example, Banaji and Greenwald (2013); Gentner, Holyoak, and Kokinov (2001); Hofstadter and Sander (2013); Holyoak and Thagard (1995); Izuma et al. (2010); Thibodeau and Boroditsky (2013).

5. See Abrams (2013, 2015a, 2015b); Alam et al. (2010); Boyd and Richerson (1985, 1987); Castro and Toro (2014); Cavalli-Sforza and Feldman (1981); Claidière, Scott-Phillips, and Sperber (2014); Claidière and Sperber (2007); Fogarty, Strimling, and Laland (2011); Henrich and McElreath (2003); Kashima (2000); Mesoudi and Whiten (2004); Sperber (1996).

6. The material in this section is based primarily on C. Geertz (1981); Janssen (2007); Lansing (2006, [1991] 2007); Lansing et al. (2009); Lansing and de Vet (2012); Lansing and Kremer (1993); Lansing, Kremer, and Smuts (1998), except where noted.

7. An alternative strategy was tried at the recommendation of Green Revolution planners in the 1960s and 1970s: Many farmers planted continuously, using new rice varieties and pesticides. After numerous attempts to fine-tune this strategy to avoid extremely poor results, the strategy was dropped, and Balinese rice farmers returned to the traditional methods sketched here.

8. See also Janssen (2007); Lansing and Fox (2011); Lansing, Kremer, and Smuts (1998).

9. This model was written primarily by Marco Janssen (2012), who was kind enough to make his model publicly available. I subsequently made modifications. More precisely, these figures show results of the BaliPlus model described below—which is based on Janssen's model—but with all of my extensions to Janssen's model disabled and with graphics tailored for the present display. My students Blake Helms and Jackson Hyde also modified the code, helping to develop the graphics for Figures 7.2 and 7.3, among other things.

10. Like the simulations described below, this simulation run used only those five planting sequences in the model that used only traditional, pre–Green Revolution rice varieties.

11. Also, in some runs, the average harvest drops a little when the large cluster of subaks in the lower-left corner of the display settles on a single planting schedule. Apparently, it is locally better for each subak to choose the same planting schedule as its neighbors in this cluster because that reduces pest growth. The result is that too many subaks are planting at the same time, so water use in the watershed is not optimal.

12. Richerson and Boyd (2005) call such explanations "why-maybe" explanations. Huneman (2014) calls them "candidate" explanations.

13. In recent work (Lansing et al. 2014; Lansing and Fox 2011; Lansing and Miller 2005), Lansing and his colleagues have argued that there are important cultural differences between upstream and downstream subaks. These are differences in attitudes and values that have to do with ways in which subaks interact in the water coordination system. I do not address these differences.

14. There appears to have been significant influence from Java, which is adjacent to Bali, by at least the ninth century C.E. (Lansing 2006), although there is evidence of much earlier contact with Indians or other Asians (Lansing et al. 2004).

15. In later papers Lansing and his colleagues gave further arguments against the hypothesis that planting schedules were centrally managed, even in the Sungi watershed (Lansing and de Vet 2012; Lansing and Fox 2011).

16. In simulations that I do not describe here, I have used methods introduced in Abrams (2013) to investigate processes by which analogies might have played a role in the spread of new religious patterns in Bali.

17. A new model of Balinese water and crop management by Lansing et al. (2017) also incorporates randomness in planting schedules due to disruptive behavior. This randomness has a different purpose in Lansing's model,

so his model does not include a factor that plays the capriciousness-suppressing role that religion does here. Though direct comparison of parameters in Lansing's model and the one described here is difficult, I believe that the amount of random disruption in his model is effectively less than in mine and may be analogous to the capriciousness remaining in the present model after new religious patterns have become widespread.

18. Lansing et al. (2009) report that the earliest evidence of possible rice cultivation in Bali is from about 2660 years ago and argued that it is more realistic to think that rice cultivation began 2000 years ago. I actually ran the models for 5000 years after the 500-year burn-in but only report the first 2000 years here. Results for the full 5000-year runs are qualitatively identical to what I present here. As discussed below, the amount of communication about religious variants in the model is not calibrated to data about actual communication, so it may be appropriate to think of years in the model as simply abstract markers of time. Nevertheless, I prefer to focus on a realistic number of years because the stochastic dimensions of the model that come from the vagaries of pest and water distribution are calibrated to actual years. I discuss this further in the penultimate section of the paper.

19. My students Blake Helms and Jackson Hyde ran most of the simulations.

20. This was also an assumption implicit in the group selection hypothesis.

21. I chose 0.3 as the base probability of choosing a random planting schedule and reduced the impact of the religious variant by two-thirds because these values allowed variation in other parameters to produce a wide range of interesting behavior.

22. For further details on the meaning of these parameters, see Janssen (2007), Lansing and Kremer (1993), and the documentation that comes with Janssen's (2012) model.

23. Most of these simulations were performed by two of my students, Christopher Blake Helms and Jackson Hyde.

24. Janssen (2007) used a different way of quantifying the pest dispersal rate. *pestdispersal-rate* = 1.0 in the NetLogo model corresponds to $d = 0.3$.

25. The other one is the high pest, high rain configuration.

26. A color plot illustrating this point is available from the author.

27. Since it may be common for there to be a great deal of fluctuation in religious patterns in some societies, the fact that BaliPlus illustrates this possibility is interesting. According to Hildred Geertz's (2004) description of

Balinese villages in the 1980s, a wide variety of nominally inconsistent variations on traditional (Hindu-based) Balinese religious patterns coexisted and interacted.

28. I initially experimented with various Gaussian distributions but had more success with beta distributions, which allow greater control over distributions' shapes.

29. In Abrams (2017) and Abrams (unpublished manuscript), I argue that some biological mechanisms and evolutionary processes may involve what is called *imprecise probability* (e.g., Fierens, Rêgo, and Fine 2009), a generalization of probability. Every process in BaliPlus is either deterministic or probabilistic in the usual sense, which would imply that there are no imprecise probabilities in BaliPlus. Nevertheless, I think it may be possible to argue that patterns of harvest success in BaliPlus have certain properties that would also be common in processes involving imprecise probabilities but uncommon in those involving probabilities. This is an issue for future investigation.

30. Some of Howe's (2001) remarks about religion in Bali suggest that for many Balinese, religion has in recent years become a distinct cultural domain.

31. I am grateful to Bill Wimsatt and Alan Love for detailed, helpful comments on an earlier draft of this paper and to Bill for earlier feedback; to Blake Helms and Jackson Hyde for work on the BaliPlus source code and for running the simulations; to Stephen Lansing for answering questions about his work and sharing unpublished material; to Marco Janssen for making available his NetLogo version of Lansing and Kremer's model and for answering questions. Others who provided helpful feedback include Adrian Currie, Barbara Wimsatt, Bill Dressler, Bret Beheim, Brett Calcott, Byron Kaldis, Cailin O'Connor, Christopher Lynn, Colin Garvey, Dan Grunman, Daniel Singer, David Henderson, Heidi Calloran, Jason DeCaro, Jim Bindon, Kathryn Oths, Lesley Weaver, Margaret Schabas, Mark Risjord, Melissa Brown, Michael Weisberg, Michiru Nagatsu, Murray Leaf, Paul Smaldino, Pete Richerson, Tyler Curtin, Yoichi Ishida, as well as others at several presentations. I owe my interest in Lansing's work to Emily Schultz's recommendation; conversations with Emily have influenced my thinking in ways that are reflected in this chapter but that may not be apparent. Finally, I am sincerely grateful to the University of Alabama at Birmingham IT Research Computing unit for making time available on the Cheaha computing cluster. Here is an official statement of acknowledgment:

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