Chapter 5
A Conceptual Framework for Analyzing Social-Ecological Models of Emerging Infectious Diseases

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5.1 Introduction

Unraveling mechanisms that underlie new and reemerging infectious diseases (EID) requires exploring complex interactions within and among coupled natural and human (CNH) systems. This scientific problem poses one of the most difficult challenges for society today (Wilcox and Colwell 2005). EID are diseases that have recently increased in incidence or in geographic or host range (e.g., tuberculosis, cholera, malaria, dengue fever), and diseases caused by new pathogens and new variants assigned to known pathogens (e.g., HIV, SARS, Nipah virus, and avian influenza) (Morse 2005). Wilcox and Gubler (2005) and Wilcox and Colwell (2005) argue that transformations in ecological systems caused by multifaceted interactions with anthropogenic environmental changes such as urbanization, agricultural transformations, and natural habitat alterations produce feedbacks that affect natural communities and ultimately their pathogens, animal host, and human populations. These altered "host-pathogen" relationships facilitate pathogen spillover into "new" hosts, rapid adaptations by pathogens, more frequent generation of novel pathogen variants that result in new and reemerging infectious diseases, as well as range expansion and increasing epidemic intensity and frequency of existing diseases.

In this chapter we present a conceptual framework for examining the Wilcox-Gubler-Colwell hypothesis in the context of whether risks, and perceptions of risk,

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M.J. Manfredo et al. (eds.), *Understanding Society and Natural Resources*,
DOI 10.1007/978-94-017-8959-2_5,

associated with highly pathogenic avian influenza (HPAI) caused by the H5N1 virus,[1] as measured in terms of poultry deaths, can be associated with anthropogenic environmental changes produced by urbanization, agricultural change, and natural habitat alterations. This is a novel way of looking at HPAI and other health risks like it, suggesting these risks are not an accident of time and place, but rather are the product of the modernization and urbanization transitions.

We present the conceptual framework in the context of Vietnam because (1) it has been one of the nations most affected by HPAI, (2) has a rapid rate of development, and (3) has very comprehensive secondary databases relevant to such studies. The emergence of the HPAI was first reported in Vietnam at the end of 2003 (Delquigny et al. 2004). Three major epidemic waves of HPAI have occurred in poultry, resulting in 45 million birds culled between December 2003 and August 2005, leading to a 0.5 % reduction in GDP in 2004. As of 2012, a total of 123 confirmed human cases and 61 deaths were recorded (World Health Organization 2012). The country has attempted to control the infection through massive, repeated vaccination campaigns in combination with other control measures (Gilbert et al. 2008a). Vietnam is a particularly useful country to examine development transitions and their associated environmental transformations because these processes are occurring both exceptionally rapidly and simultaneously as traditional agricultural lands are converted to intensified commercial farming or reshaped into urban settlements to meet the needs of the growing population attracted to cities for emerging job opportunities (Douglass et al. 2002; Spencer 2007). If development transitions do pose new challenges to governance, and in particular environmental health challenges, then one would expect to see more of these types of problems in transitional agricultural or peri-urban areas as distinct from both predominately urban and rural areas.

The Wilcox-Gubler-Colwell hypothesis of disease emergence was influenced by complexity theory, which argues that as complex adaptive systems (CAS) CNH systems exhibit far-from-equilibrium non-linear behavior often manifested as “surprise” as with the case of abrupt and unexpected epidemiological phenomena including the emergence of entirely new diseases. Parallel to this, in biological science a re-envisioning has occurred in which nature is no longer seen as consisting of balanced ecological systems made up of relatively linear processes. Rather, natural systems are now seen as hierarchical, self-organized, non-equilibrial and non-linear systems in which emerging diseases can themselves be seen as “emerging properties” of these CAS (Levin 1999). The traditional conception of the ecosystem, a fundamental paradigm in the ecological sciences, has thus been overturned (O’Neill 2001).

As such, ecosystems, including “social-ecological systems” are now understood as characteristically producing emergent phenomena like the unexpected appearance of new pathogens, inherently unpredictable by conventional approaches and theory (e.g., epidemiological models). Moreover, nearly all emerging diseases are vector borne or zoonotic (i.e., maintained in natural host-pathogen cycles that “spill over” to humans) (Woolhouse and Gowtage-Sequeria 2005). They, or their immediate progenitors, exist as part of naturally co-evolved host-parasite complexes

[1] In this chapter HPAI refers to HPAI caused by the H5N1 strain.

embedded within ecosystems, whose dynamics normally include non-linear, cross-scale behavior (Horwitz and Wilcox 2005). Based largely on complexity theory, social ecological systems and resilience (SESR) theory was developed to account for the non-linear dynamic behavior of CNH systems that result from intervention in "managed" ecosystems that unwittingly lead to unexpected and sometimes catastrophic outcomes, including disease re-emergence.

Holling (1973) introduced the concept of resilience into the ecological literature as a way of understanding nonlinear dynamics, such as the processes by which ecosystems maintain themselves in the face of change. In a resilient forest ecosystem, for example, four phases of change repeat themselves again and again. The first two phases, exploitation (the establishment of pioneering species) and conservation (the consolidation of nutrients and biomass), lead to an old growth forest or a climax community. But this climax community invites environmental disturbances such as fire or disease, and is more susceptible to disturbances than non-climax forests. When surprise or change occurs, the accumulated capital is suddenly released producing other kinds of opportunity, termed creative destruction. Release, a very rapid stage, is followed by reorganization in which, for example, nutrients released from the trees by fire will be fixed in other parts of the ecosystem as the renewal of the forest starts again (Berkes et al. 2003). Holling suggested that human societies also reproduce and reinvent in the process of cyclic transformations; he writes: "The bewildering, entrancing, unpredictable nature of nature and people, the richness, diversity and changeability of life come from the evolutionary dance generated by cycles of growth, collapse, reorganization, renewal and re-establishment" (Holling 2003: xv).

5.2 Integrating Social Science Theories Relevant to Development Transitions

Several social science theories relevant to the notion of types of development transitions are also relevant to both the Wilcox-Gubler-Colwell hypothesis and Holling's resilience theory. Our starting point is the theory of the Environmental Kuznet's Curve (EKC) from the discipline of development economics. Nobel Prize winner Simon Kuznets proposed that with respect to inequality, economic development is not linear but rather an inverted 'u' shape; economic development is a transition from an initial state of relative equality to an end state also of relative equality, but in the midst of economic development nation-states display high levels of economic inequality (line C in Fig. 5.1 is a Kuznets curve). While various scholars have shown that Kuznets curves are not universally applicable (see Park et al. 2007), Kuznets curves have become a simple but powerful method for empirically testing hypotheses about transitional states. The EKC hypothesizes that certain indicators of environmental degradation tend to get worse as modern economic growth occurs until average income reaches a certain point over the course of development (Grossman and Krueger 1995). Urban air pollution and deforestation have been cited as examples of environmental quality variables that follow the EKC. Recent

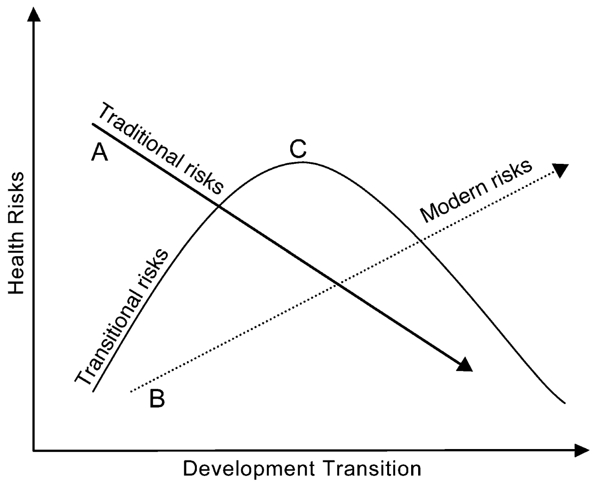

Fig. 5.1 Environmental risk transition framework

empirical work has applied this understanding to the issue of HPAI (Spencer 2013), indicating that disease occurrence may be most likely where settlements are undergoing the most intense transitions. Such evidence suggests that a deeper understanding of "transition" is warranted.

While some environmental quality indicators such as landfills and biodiversity do not seem to follow the EKC, supporters of the theory have argued that this may be more to do with issues of scale. Traditionally, most of the empirical work on EKC has been based on inter-country analysis of cross-sectional data. Often global regions (groups of countries) have been the unit of analysis. Most commonly, the metrics chosen for the predictor variable have been Gross Domestic Product (GDP) or GDP per capita, often adjusted by purchasing power parity or the Human Development Index (HDI). To address the scale issue we are examining whether the EKC is valid at the lowest level of government administration–the commune or municipal ward—for the entire country of Vietnam using readily available census data. The outcome variable is HPAI in domestic poultry. We are faced with the challenge that at the commune/ward level metrics such as GDP or HDI are not valid or are difficult to measure (e.g., because data are not available). Furthermore, using a binomial variable—whether a place is rural or urban (as classified by the government) has two problems: (1) one cannot test the non-linearity of the curve and (2) it contradicts our fundamental premise that a significant number of places are not easily classifiable as being either rural or urban. Thus, we are forced to find a new metric reflecting development, which is ordinal with at least three levels. The "urbanicity" method from the field of urban geography is useful for classifying place (Allender et al. 2008; Dahly and Adair 2007; McDade and Adair 2001; Vlahov and Galea 2002). Though most of the urbanicity metrics in the literature are continuous scale metrics, we adapt the principles to create an ordinal scale metric.

Another social science theory relevant to understanding the relationship between development transitions and EID comes from Smith (1990), who proposed an environmental risk transition where the environmental factors leading to ill health were categorized as traditional or modern. This categorization is based on the premise that the major environmental causes of traditional diseases are problems at the household level (e.g., water, sanitation, food availability and quality, ventilation and indoor air pollution). As these are addressed during development there is an increase in the relative importance of the major environmental causes of more modern diseases which operate at the community level (i.e., urban air quality, occupational hazards, toxic chemicals, and motorization). As these are addressed in richer societies a further transition occurs to increase the importance of environmental hazards at the global level (e.g., global warming, land-use change) (Holdren and Smith 2000; McGranahan et al. 2000; Smith and Akbar 2003).

Figure 5.1 shows the environmental risk transition framework in which traditional risks fall with social and economic development, transitional risks rise and then fall, and modern risks rise throughout the development process. Smith and Ezzati (2005) write that limited or no research has attempted to apply this framework to emerging and reemerging infectious diseases caused by evolving human activities such as those associated with trade, tourism, terrorism, and human interactions with natural environments.

Others have hypothesized forest (a natural habitat) (Grainger 1995; Mather 1992, 2007; Rudel 1998), agrarian (Hall 2004; Rigg 2005), and urban (Douglass 2000; Friedmann 2005) transitions. A forest transition occurs when an initial surge in economic activity spurs deforestation, but as economic activity continues to intensify and cities grow larger, a 'turnaround' occurs, and deforestation gives way to reforestation. The agrarian transition has been defined as a number of inter-related phenomena. These include agricultural extensification and intensification (the amount of agricultural land is hypothesized to follow a Kuznets curve as extensification precedes intensification, but intensification then leads to the abandonment of marginal land); increased integration of production into market-based systems of exchange; heightened mobility of populations both within and across national borders as people are attracted to opportunities both within and outside of the agricultural sector; and processes of environmental change that reflect new human impacts and new valuations of resources (Akram-Lodhi 2004; Rigg and Vandergeest 2012; De Koninck 2004). The urbanization transition includes two parallel processes: population concentration (population is hypothesized to increase linearly) and the development of socio-physical infrastructure to manage the inevitable conflicts and problems associated with higher density living (infrastructure is hypothesized to increase linearly). The urban transition in developing countries describes societies that have rapidly changed from rural to urban forms of social and physical organization in relatively short time periods (Douglass 2000; Montgomery et al. 2004) such as those found in Southeast Asia.

The broader implications of these simultaneous and related transitions remain unexplored in general, and more specifically, as Wilcox and Colwell (2005) argue, in relation to how they produce feedbacks that affect natural communities and ultimately their pathogens, animal host, and human populations. A better understanding of the relationship between development transitions and EID is critical for improving our ability to predict and respond to EID. This is particularly true in Vietnam where government policies have facilitated what can broadly be called a "transition to the market" (Arkadie and Mallon 2003; De Vylder 1990; Fforde and Vylder 1996). Economic policies have driven changes in the built environment that have created new ecological health risks (Oliveira et al. 2004; Smith 1997), migration to cities has simultaneously uprooted residents from local social networks and placed them into new neighborhood associations, water user-groups, and other forms of social organization (Crane 1994; Spencer 2007). These new socio-physical ecologies present new challenges that, in turn, require new forms of social organization and governance, many of which do not yet exist, to provide basic services such as water and sanitation, education, housing, and public health.

A final social science perspective that has received little attention to date in the developing world relates to theories of behavioral decision making and perceptions of risk. This field draws primarily from economics, psychology, philosophy, anthropology, and cognitive science. Researchers have developed tools such as the Social Amplification of Risk Framework (Kasperson et al. 2003; Pidgeon et al. 2003) to describe and explain the societal processing of risk signals, but tests of such frameworks are rare because of the difficulty in predicting when risk amplification conditions are likely to occur (Frewer et al. 2002). A central insight of decision theory is that risk responses are based on socially constructed perceptions of risk. That is, risk means different things to different people; it cannot be measured independent of our minds and cultures. People prioritize risks in different ways, depending on their beliefs about the need to try to reduce a risk (Douglas and Wildavsky 1982; Hofstede 1984; Park et al. 2007). Research conducted in the developed world suggests that perceived risk is related strongly to feelings of control and trust (Slovic 2000). Some authors suggest that people perceive low risk during modernization because they feel they are in control of technology, nature, or society and that regulatory authorities can be trusted (Bauman 1992; Beck 1999; Giddens 1992). Over time, however, perceived risk increases as feelings of control and trust are eroded. Some people will respond swiftly and comprehensively to a risk event and others will respond more slowly, depending on a range of psychological and socio-cultural variables and environmental conditions. However, the relative importance of various elements in CNH systems (i.e., socio-ecological and socio-psychological factors) in determining perceptions of and responses to the risk of EID in rapidly developing societies has not been examined.

To understand the relationships between characteristics of decision makers, their environmental context, and their risk responses, the field of decision science uses a wide range of methodological approaches and analytical tools. Qualitative interviews and focus groups permit an in-depth exploration of risk perceptions and responses, allowing participants to describe beliefs and experiences in their own words, rather than as a choice between predetermined survey responses (Pope and Mays 1995). These methods are useful in defining the range and variability of conceptualizations of risks such as disease outbreaks and how they might relate to environmental change (O'Brien 1993). Quantitative methods (e.g., decision analysis, process tracing, surveys) are more readily applied with larger samples and allow precise measurement of the information integration strategies decision makers use to determine their risk response. Applied to the problem of understanding the relationship between modernization and EID, we can test whether variation in individuals' risk responses is related to environmental change as represented in our degree of modernization metric.

Combining decision and risk research methods applied at the household level with environmental economics methods applied at the commune- and national-level analyses provides an opportunity to look for converging evidence for hypothesized relationships between constructs in our social-ecological model of EID. Identifying variation in risk responses to EID is only of theoretical interest if it furthers our understanding of the causal variables and structure in the coupled natural-human system that lead to the behavior. An understanding of the system is also crucial to making such results practically useful. For instance, observing variance in HPAI risk responses in Vietnam provides an empirical basis for making predictions about other diseases and other developing countries that have not been studied directly.

In sum, the conceptual framework introduced in this chapter relies heavily on the integration of multiple social science theories and methods from diverse disciplines (e.g., environmental economics, geography, decision and risk science, urban and regional development, and spatial information science). Identifying key components of these theories relevant to the notion of types of development transitions provides a coherent approach to analyzing the complex interactions among natural and human systems at diverse spatial, temporal, and organizational scales. In the next section we provide reasons for the choice of important elements to characterize CNH systems.

5.3 Anthropogenic and Ecological Determinants of HPAI in Southeast Asia

Kapan et al. (2006) hypothesized that the on-going process in Southeast Asia of replacing traditional farming methods such as multi-species livestock husbandry with industrial, mass-production-oriented operations poses significant environmental health risks (e.g., Mallin and Cahoon 2003) due to increases in livestock pools and thus opportunities for disease transmission. Simultaneously, rapid urban and peri-urban development in these countries has often been accompanied by more refuse, standing water, and animals in and around homes that have been correlated with environmental health risks (e.g., Graham et al. 2004). With respect to HPAI, expansion of the urban fringe has placed a larger proportion of the human population in contact with formerly dispersed farm environments that include potentially infected poultry and swine populations. Such urban–rural interfaces have been hotspots of other infectious diseases such as leishmaniasis (Oliveira et al. 2004).

An array of anthropogenic and ecological studies of the determinants of HPAI in Southeast Asia has supported these hypotheses. Gilbert et al. (2006, 2007) showed that the interaction of poultry and particularly domestic duck populations within the rice paddy production system was as an important factor for the maintenance and spread of HPAI virus in Thailand. Pfeiffer et al. (2007) showed that rice paddy production intensity and density of domestic chickens and water birds were also associated with a higher risk of HPAI outbreaks in Vietnam, lending support to the rice-duck-chicken hypothesis. The same study showed that increased distance from high density human population areas consistently decreased HPAI risk (Pfeiffer et al. 2007). The study finds support for the hypothesis of "the presence of a fairly widespread infection reservoir in Vietnam …, possibly in domestic and wild water birds" (Pfeiffer et al. 2007). Gilbert et al. (2008b) demonstrated that a few key factors such as human population density, rice cropping intensity, and to some extent poultry density, managed to explain a large proportion of the spatial variation in HPAI disease risk; the same study also notes that considerable variation remained unexplained, and suggests that other factors such as poultry production and marketing systems, agricultural seasonality, the potential for contacts between domestic and wild birds, and climatic and other conditions affecting the persistence of the virus in the environment should be considered. Fang et al. (2008) found the minimal distance to the nearest national highway, annual precipitation, and the interaction between minimal distance to the nearest lake and wetland, were important predictive environmental variables for the risk of HPAI in China. A study of post-vaccination outbreaks in southern Vietnam found poultry flock density, fraction of houses with electricity, rescaled Normalized Difference Vegetation Index, buffalo density and sweet potato yield to be significant risk factors (Henning et al. 2009).

Of particular interest to this study is the claim by Gilbert et al. (2014) that the highest risks of HPAI impact in Southeast Asia are to be expected where extensive and intensive systems of poultry production co-exist. The extensive systems allow virus circulation and persistence; the intensive systems promote disease evolution. A study in Thailand found differences in avian influenza risk rates across scale of operations (Otte et al. 2006), which was attributed to bio-security (waste management) features.

Spencer (2013) sought to establish whether bird deaths followed a Kuznets curve as settlement infrastructure patterns evolved. Vietnam's 1999 Census of Population and Housing provides counts of households by housing construction materials (traditional/temporary or modern), water supply (stream, rain, well, piped), and sanitation infrastructure (none, pit, composting, flush). Spencer converted each of these 4-category, ranked urbanization measures into four distinct measures of settlement "coherence". For each coherence measure, greater mixing (i.e. incoherence) of the four categories was set to center on a value of zero, with more "traditional" settlement a mixture dominated by the least sophisticated (e.g. no toilet) of each response category valued at (−1), and the most "modern" settlements a mixture dominated by the most sophisticated (e.g. running water) of each response category valued at (+1). Working at the district level, Spencer plotted these three coherence indices, as well as a composite index combining the three, against the probability that a district in any of Vietnam's provinces (including cities) had an outbreak of HPAI in 2004 or 2005. After accounting for a minimal threshold effect of development, Spencer (2013) found a distinct Kuznets relationship exists between settlement coherence and HPAI. In particular, the sanitation coherence index explained over one third of variance in outbreaks (R-square = 0.37, bivariate), and the water supply coherence index explained over half (R-square = 0.56, bivariate). Overall, the findings suggest that the urban infrastructure transition is associated with HPAI outbreaks in poultry and may be used as a general predictor of emerging infectious disease risk.

These initial findings illustrate the potential theoretical contributions of a transitional approach to the study of HPAI. This suggests that for the urbanization measure, at least those measures centered on water supply and sanitation, the basic function may be a Kuznets curve rather than a linear or a more complex curve. Our current project is conducting similar exercises for agricultural change and habitat alteration. We are developing transition indices for agricultural change and habitat alteration, plotting them against the probability of HPAI outbreak, and choosing the curve that best fits the data. A twice-changing slope as the best fit would suggest a more complex fluctuation of risk between traditional and modern landscapes, and a u-shaped curve would suggest that transitional landscapes are associated with reduced risk.

Lastly, we are examining how perceptions of HPAI risk vary with urbanization, agricultural change, and habitat alteration. Of the few studies that have examined determinants of HPAI risk perceptions, all have focused on perceived risk of HPAI to humans (rather than perceived risk to the health of poultry). Three studies conducted in Asian countries (de Zwart et al. 2007; Fielding et al. 2005; Figuié and Fournier 2008) showed perceived human risk was correlated with demographics (women and older people perceived more risk) and efficacy (perceived availability of protective actions and ability to engage in those actions led to lower perceived risk). In Laos, Barennes et al. (2007) reported that protective behavior was more likely with higher levels of education, urban living, knowledge of HPAI, and owning poultry. Only one of the above studies (Figuié and Fournier 2008) was conducted in Vietnam. No studies have examined the relative importance of socio-ecological variables (urbanization, agricultural change, habitat alteration) versus socio-psychological variables (efficacy, knowledge, affective response, risk avoidance, demographics) in determining perceptions of risk to the health of poultry. Moreover, no studies have examined whether risk perceptions and protective behaviors vary across traditional, transitional, and modern settings or with observed risk (poultry deaths).

The framework we are proposing is based on an assumption that risk management policies need to be derived from a broad-based understanding of how decision makers perceive, explain, and prioritize risk. An analysis of EID risk that focuses only on socio-ecological variables will not reveal the socio-psychological differentiation of individuals who are more or less successful in responding to and managing EID outbreaks. Currently, however, there exists a gap in knowledge about the underlying mechanisms that explain variation in perceptions of the risk of EID and how these perceptions vary with social-ecological transition. Furthermore, most research on perceived risk has been done in democratic, Western countries, not in a context where there is tight state control of key institutions that interpret and disseminate disease risk information. To further understand how EID risk signals are processed by individuals in the context of CNH systems in Vietnam, we need to examine in depth the processes through which people collect and integrate data from natural and human systems. This work will advance basic knowledge about the complex linkages among ecological, social, and psychological variables that amplify or attenuate the intensity and frequency of EID.

In sum, literature suggests an array of important elements characterize CNH systems. Using unidimensional measures, Spencer (2013) showed that the relationship between transition and disease can be examined empirically. However, more research is necessary to understand the complex interactions among natural and human elements at diverse spatial, temporal, and organizational scales, and how they relate to EID outbreaks.

5.4 Developing and Testing the Framework

Empirical studies on CNH system change and disease emergence depend on the assembly of a diverse set of independently generated neighborhood- and landscape-level data accurately matched with spatially aggregated or 'point' level data. In order to make such analyses possible we need an extensive spatial database that includes vector layers representing landscape characteristics (e.g., ecoregions, geology, soils, protected area boundaries, human settlements, road infrastructure) from available hardcopy maps, digital data, aerial surveys, global positioning system (GPS) data, and satellite image feature extraction, e.g., urban features (Zhang et al. 2002) and paddy fields (Xiao et al. 2005, 2006). We have also acquired national census data and other economic, demographic, institutional and cultural databases that describe socioeconomic variables at the household and commune level and that have been linked to biophysical data via a geographic information system (GIS) (Epprecht and Heinimann 2004; Epprecht and Robinson 2007). These databases can also provide information on the location and size of villages, roads, streams, and agricultural fields. Information collected on specific landscapes through interviews with farmers and key informants can be keyed to these databases using handheld GPS devices.

We can use these multivariate databases to test models of general relationships hypothesized between HPAI and urbanization, agricultural change (both crop land and poultry), and habitat alteration at the national level using commune level data. For instance, we can test an *a priori* specific structural equation model (SEM) based on extant literature. In Fig. 5.2, we present a model in which we hypothesize that outbreaks of HPAI in poultry are associated with variations in three latent constructs: (1) Urbanization, measured in terms of changes in quality of housing and drinking water supplies (Spencer 2013); proximity to cities (Pfeiffer et al. 2007) and major roads (Fang et al. 2008), and human population (Gilbert et al. 2008b); (2) Habitat Alteration, measured in terms of changes in wetlands (Fang et al. 2008; Gilbert et al. 2007), amount and diversity of natural water sources (Fang et al. 2008);

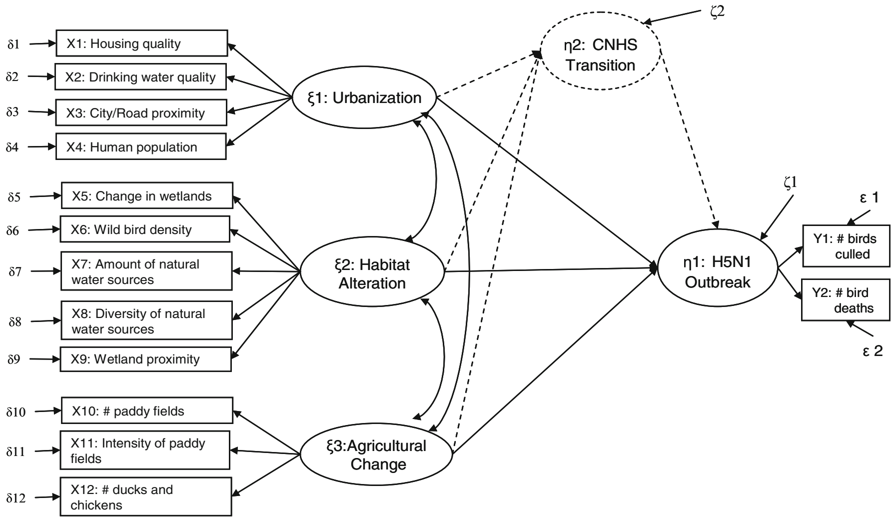

Fig. 5.2 Structural equation models (SEMs) of hypothesized relationships between HPAI outbreak and urbanization, habitat alteration, and agricultural change (both crop land and poultry) at the national level. Model 1 (*solid lines*) proposes an *a priori* SEM based on existing literature; model 2 (*dashed lines*) proposes an explanatory higher-order factor

changes in proximity to wetlands (Fang et al. 2008); and (3) Agricultural Change, measured in terms changes in terms of number and intensity of paddy fields (Gilbert et al. 2007, 2008b; Pfeiffer et al. 2007), and number of ducks and chickens (Gilbert et al. 2006, 2007, 2008b; Pfeiffer et al. 2007).

The second model shown in Fig. 5.2 (dashed lines) tests whether the relations among urbanization, habitat alteration, and agricultural change are attributable to a common higher order influence. While the first model acknowledges the existence of relations among the three latent constructs, it does not explicitly represent cause of covariation. The second model postulates that correlations among the latent constructs can be explained by a higher-order factor. We can thus examine direct and indirect pathways between the latent constructs and HPAI outbreak. The dashed lines in Fig. 5.2 represent the indirect pathways and higher-order factor, which we call CNH system Transition.

Evaluating these models is quantitatively challenging because the concepts of urbanization, agricultural change, and habitat alteration represent a complex multivariate response. Multiple regression analysis of these types of problems are subject to problems of interpretation that include covariances among interacting explanatory variables and an inability to assign unique explanatory capacity to individual factors (Grace and Bollen 2005; Laughlin and Abella 2007). To avoid these problems, techniques such as structural equation modeling (SEM) may be most useful. SEM allows researchers to theorize about why explanatory variables are correlated and to build directional relationships into their models of systems. Explanatory variables are often correlated because they have a common cause or because one factor influences the other (Laughlin and Abella 2007; Shipley 2000). These situations are common in observation studies of complex systems. Consequently a systems approach to the analysis and interpretation of composition in this CNH system may be optimal for explaining where driving forces interact to produce observed patterns of bird deaths across the landscape.

We can not only explore the relationship between HPAI and urbanization, agricultural change, and habitat alteration at the national level, but also examine whether this relationship exists at commune and household scales using focus groups, interviews, and a structured household survey. This is necessary because as numerous researchers have shown, complexity is scale sensitive (Fox 1992; Phillips 1999; Walsh et al. 1999). Processes that operate at one scale may not occur at other scales or resolutions.

5.5 Lessons Learned About Social Science Integration

Social science integration poses many challenges. First, there is a steep learning curve regarding terminology and methods for interdisciplinary research teams. For instance, "risk" may be expressed in monetary terms by an environmental economist, as probability by a statistician, or as a more qualitative and multi-dimensional construct by a decision theorist. These differences of course have important implications for choices about the measures collected and analyzed. Our team meets this challenge by holding frequent (often biweekly) meetings throughout proposal development and project implementation to identify and learn differences in our understandings and approaches.

Another challenge for social science integration is the need to measure complex phenomena such as "modernization," which often occur on very large scales. Our approach is to recognize the subjectivity and the value-laden judgments that scientists make about the validity of alternative measures. Accordingly, we recommend selecting variables directly from relevant theories and statistically testing (e.g., through factor analysis) the extent to which sets of variables combine in an internally consistent manner. The higher the consistency, the more confidence we have that the measures capture an underlying construct relevant to our model.

To illustrate, our primary goal for measuring the complex construct of "modernization" is to create a "degree of modernization" national map based on the smallest administrative unit as the unit of analysis and use secondary data sources to do so. We start by identifying three latent concepts for modernization—urbanization, agricultural intensification and land use changes. For each of these concepts, we identify theories and metrics from diverse fields and then select those variables which seem to be valid for the type of transition happening in Vietnam. This list is shortened simply by eliminating variables for which high quality secondary data do not exist. The next step in the process is to realize that we are creating a comparative rather than an absolute metric of modernization. Even though the metric helps in the comparative assessment of the level of modernization, there is still a need to validate it based on ground-truthing. So then we use a multi-disciplinary approach to ground truthing—walk through field surveys, random ground-level photographs, satellite imagery, commune data archives—to ensure that our classification was at least accurate on an ordinal scale.

A final key element facilitating the integration of diverse social sciences relates to the disciplines represented by the research team. Our core team is comprised of researchers from fields that already reflect an interdisciplinary approach (geography, urban planning, environmental science, and decision science). Also, each team member has experience working at different scales. We are fortunate to work in an institutional setting that encourages interdisciplinary work and multiply authored papers. Support for publishing in cross disciplinary journals helps generate recognition for the value of integrated work.

5.6 Conclusion

No single theory or method is sufficient to explain complex phenomena such as EID and the relationships between factors influencing disease outbreaks. Integrated approaches—bridging multiple social sciences and bridging social and non-social sciences—are time consuming and challenging enterprises, but arguably the most fruitful if they provide an in-depth description of and improved predictive capacity for a complex problem. The initial framework we present for the analysis of social-ecological models of EIDs is useful for scholars from diverse disciplines as a method for examining the relationships within and among multiple components of CNH systems. Given that other researchers have already identified the relevance of these components for explaining HPAI, we have some confidence in our model as a starting point. Future research will need to examine the extent to which relationships among these components meaningfully capture the construct of transition and explain HPAI outbreaks in Vietnam.

Once a model has been proven robust, we will be able to examine specific conditions and identify specific components of CNH systems that amplify or attenuate HPAI risk. More systematic analyses of CNH systems will improve our understanding of how transformations in social-ecological systems produce feedbacks that affect natural communities, their pathogens, animal host, and human populations at diverse spatial, temporal, and organizational scales.

Given its importance and difficulty, we conclude that social science integration requires a carefully considered theoretical rationale and a model-guided methodological approach. This approach will provide for cumulative results from multiple studies designed to investigate various aspects of the model. To test the robustness of this approach, interdisciplinary research teams will need to examine the consistency of results across independent data sets, ideally with different operationalizations of the relevant theoretical constructs.

By further developing and applying conceptual frameworks that take into account the complexity of real-world systems we can build the knowledge base necessary to advance our understanding in a manner meaningful to policy makers. Ultimately, such frameworks offer a flexible tool for diagnosing and dealing with the multiple challenges facing rapidly developing communities.

Acknowledgments Author order is alphabetical; the authors contributed equally to the development of this manuscript. The authors acknowledge Drs. Nancy Lewis, Bruce Wilcox, Michael DiGregorio, and Durrell Kapan for their contributions to conceptualization of the framework. We are grateful for support from the East-West Center, Honolulu HI, and the National Science Foundation through grant 0909410.

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