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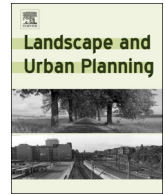
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Research Paper

Emerging infectious disease, the household built environment characteristics, and urban planning: Evidence on avian influenza in Vietnam

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ABSTRACT

Recent concerns with pandemic outbreaks of human disease and their origins in animal populations have ignited concerns regarding connections between Emerging Infectious Diseases (EID) and development. As disasters, health, and infectious disease become part of planning concern (Matthew & McDonald, 2007), greater focus on household infrastructure and EID disease outbreaks among poultry is warranted. Following Spencer (2013), this study examines the relationship between the mix of household-scale water supplies, sanitation systems, and construction materials, and Highly Pathogenic Avian Influenza (HPAI) among poultry in a developing country: Vietnam. Findings of our multivariate logistic regressions suggest that a non-linear, Kuznets-shaped urban transition (Spencer, 2013) has an independent effect on the outbreak of HPAI, especially as it relates to household-level sanitation infrastructure. We conclude that the Kuznets-shape development of household infrastructure characteristics in Vietnam play a significant role in explaining where poultry outbreaks occur. Using secondary data from the Census of Population and Housing, and the Agricultural Census at the District and Commune levels for the country of Vietnam, we performed logistic regression to test the relationship between outbreaks of HPAI in poultry and newly-developed “coherence indices” (Spencer, 2013) of household water supply, sanitation, and construction materials that measure nonlinear, transitional development. Results show that district-scale coherence indices are negatively and independently correlated with HPAI outbreaks, especially for sanitation. Findings also suggest that community-scale coherence of urban infrastructures is a powerful tool for predicting where HPAI poultry outbreaks are likely to occur, thereby providing health planners new tools for efficient surveillance.

1. Introduction

Acute global scares occurring over the past decade, from Severe Acute Respiratory Syndrome (SARS) in Hong Kong and Southern China in 2003, to Highly Pathogenic Avian Influenza (HPAI) in Vietnam and other parts of Southeast Asia starting from 2004, to Swine Flu in Mexico in 2009 suggest that the emergence of new contagious illnesses from rapidly developing regions with dense domesticated animal populations appears to have become an endemic component of the 21st Century's rapid economic development of landscapes (e.g. *Institute of Medicine, 2009; Kontgis et al., 2014; Wilcox & Colwell, 2005*). The fields of public health and medicine, with their emphasis on human health, have difficulty mounting effective responses to these new diseases because they arise in localities very quickly and unpredictably due to their origins in animals (*Institute of Medicine, 2009; Kilpatrick et al., 2006*). Since

pandemic human HPAI has its origins in avian HPAI, influenza among poultry presents the low probability risk of high-level human pathogenicity that poses a very difficult predicament for public health (*Peiris, de Jong, & Guan, 2007*).

Health scholars studying these illnesses *do* concur on the fact that they are zoonotic in origin – i.e. that they originate within wild animal populations and then somehow transfer to human populations (*Wilcox & Colwell, 2005*). Thus, if we can achieve an improved understanding of when, where, and why these outbreaks occur among poultry, then a more preventive approach can be developed in line with those calling for control of HPAI transmission among poultry as a basic response to the threat of human HPAI (*Peiris et al., 2007*). One line of thinking in this growing field argues that it is the landscapes that touch on *both* the wild spaces *and* intensively human-developed spaces that provide the most likely predictive explanations, and therefore deserve the greatest

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attention of research (e.g. Wilcox & Colwell, 2005).

2. Transitional household infrastructure landscapes as predictor of emerging infectious disease

The field of Emerging Infectious Diseases (EID) has begun to accept the importance of urbanization and long term socio-environmental change as key drivers of such epidemics among poultry and potentially among humans (e.g. Kapan et al., 2006). Oliveira et al. (2004) and Spencer (2013), for example, have respectively provided some preliminary empirical analysis using leishmaniasis and Highly Pathogenic Avian Influenza (HPAI) as cases supporting the idea that unplanned urbanization's encroachment on undeveloped lands is a driver of EID.

While it is clear that EID's such as SARS, HPAI, and Ebola are zoonotic – or originating in wild animal populations – in origin (e.g. Feare, 2007; Guan et al., 2003; Leroy et al., 2005), an understanding of fast-changing human community dynamics is needed to understand why they are “emerging” among human populations since these animal reservoirs have always existed (Institute of Medicine, 2009). What is currently needed is attention to the possibly social, built, and natural trends that may function as the *enablers* of these epidemics – as distinct from the virus itself, which in the case of HPAI easily moves between wild and domestic bird populations (Wilcox & Colwell, 2005). Such an approach emphasizing the landscapes of outbreak origin will suggest preventative tools in addition to the reactive policy tools currently available, such as quarantine, vaccination, and eradication, as called for in Kapan et al. (2006).

Answering the central question asked in this paper – to what extent is HPAI in poultry associated with, and likely a partial result of an urban transition – may enable improved policy action such as better urban planning to mitigate EID health risk. The link between planning and public health outcomes has a long history.

3. Public health and urban planning

The case of the Broad Street Pump in London (e.g. Johnson, 2006) revealed the link between a lack of clean water supplies and cholera outbreaks, and it has become common knowledge that public health and the reduction of traditional infectious diseases are important components urban planning. In recent years, there has been a renewed interest in the connections between urban planning and public health, especially as they relate to transportation, walking, and physical activity. Literature reviews have outlined their centrality to the urban planning field (Frank and Engelke, 2000; Handy, Boarnet, Ewing, & Killingsworth, 2002; Lee & Moudon, 2004; Saelens, Sallis, & Frank, 2003), while empirical studies have also demonstrated their importance (Kelly-Schwartz, Stockard, Doyle, & Scholssberg, 2004). At the same time, the field of planning and resilience, which has also come into focus in recent years has focused the field on disasters and post-catastrophe development (e.g. Berke & Campanella, 2006; Burby et al., 1999), often with a health and safety focus.

Beyond these transportation- and general disaster-resilience-oriented areas of planning, the field has also begun to consider the role of urban planning as it relates to infectious disease. In their extensive analysis of the link between planning and contemporary infectious diseases, Matthew & McDonald (2007) convincingly outline the importance of urban planning as it relates to diseases such as HIV and SARS, though their review shows that the literature generally cedes this ground to the medical and health fields. While this focus on the relationship between infectious diseases and urban planning is a welcome development, their planning recommendations generally focus on responses to disease outbreaks instead of prevention. Using the case of avian influenza and urban planning, this study examines some of the planning issues that may be related to preventing the occurrence of EID's (Wilcox & Colwell, 2005). An understanding of the transitional dynamics of rapidly growing urban areas is an important background

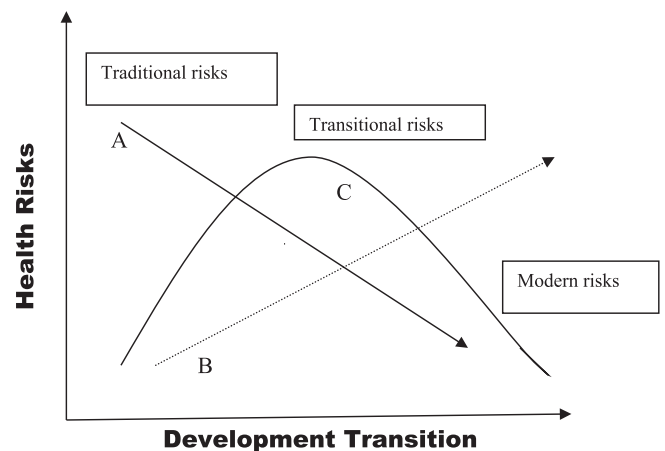


Fig. 1. Environmental Risk Transition Framework (reproduced from Finucane, Fox, et al., 2014).

trend that may be important for our understanding of EID's.

4. The Kuznets Curve, the urban Transition, and emerging infectious diseases

To understand the risks associated with transitional built environments and EID's, it is important to review the transitional dynamics of development more generally, especially since writers have hypothesized that EID emergence results from changes in the environment (e.g. Wilcox & Colwell, 2005). The Kuznets Curve (Kuznets, 1955) has long proposed that economic development is not linear with respect to economic inequality; that economic development is a transition from an initial state of relative economic equality to an end state also of relative economic equality. However, in the middle of this transition nation-states display high levels of economic inequality (line C in Fig. 1 is a Kuznets curve).

The Kuznets Curve hypothesis has also been applied to the relationship between environmental quality and economic development (Grossman and Kreuger, 1995; Shafik, 1994). An environmental Kuznets curve suggests that in a developing economy, little weight is given to environmental concerns such as deforestation or pollution. After attaining a certain standard of living, however, a nation-state's focus changes from self-interest, to social interest, and as a result forests are replanted or protected and pollution is controlled. Even though some scholars have shown that Kuznets curves are not applicable universally (see Park, Russell, & Lee, 2007), the debate has illustrated a simple and powerful method for empirically testing hypotheses about nonlinear trajectories of development.

Regarding public health transitions, Smith (1990) suggested that factors leading to ill health have changed with development. In particular, he saw a shift from traditional to modern diseases, and a shift from infectious to non-communicable disease that manifested differently across differing national contexts, but marked a relatively permanent shifting of health priorities and attention (McMichael, McKee, Shkolnikov, & Valkonnen, 2004).

Subsequently, other health scholars began to employ a more explicit spatial framework and add a third, middle category, resulting in a three-phase transition of environmental risks at the household, community and global scales (Holdren & Smith, 2000; McGranahan, Songsore, Kjellen, Jacobi, & Surjadi, 2001; Smith & Akbar, 2003). This categorization is based on the premise that the major environmental causes of traditional health hazards are often problems at the household level (e.g., poor household fuel, water, sanitation, ventilation, food quality). As these are addressed during development there is an increase in the relative importance of the major environmental causes of more modern health hazards which often operate at the community

level (e.g. urban air quality, occupational hazards). As these are addressed in richer societies a further transition occurs regarding the global health burden to increase the importance of environmental health hazards at the global level (e.g., global warming), even as traditional diseases like Bubonic Plague might re-emerge in small scales (McMichael et al., 2004).

Fig. 1 shows the environmental risk transition framework. In this framework, traditional risks fall with social and economic development, transitional risks rise and then fall with mid-level development, and modern risks rise as development reaches higher levels. A key physical component of social and economic development is urbanization (Turok & McGranahan, 2013).

The UN estimates that the world has become over 50% urban in the past decade, with the share of the world's population living in urban areas growing by 13.2% between 1990 and 2005 (United Nations, 2005), and a particularly steep increase in Southeast Asia and Sub-Saharan Africa. From 1990 to 2005, Southeast Asia's urban share grew by 38.6% and Sub-Saharan Africa's by 25.3% compared to 9.2% in Latin America, 2.3% in Europe, and 7.0% in North America. Even though some legitimately question the validity of macro-scale population projections and urbanization forecasts based on ambiguities in defining urban versus rural (e.g. Montgomery, Stren, Cohen, & Reed, 2003; Potts, 2017), the global scale of human settlement change and change in the built environment is both unquestionable and remarkable.

These high rates of urbanization in some developing countries describe societies that have rapidly changed from primarily rural to primarily urban forms of social and physical organization in relatively short time periods (Montgomery et al., 2003). The relatively high rates of change – as opposed to background levels – suggests the need to evaluate the concept of “transitional” societies and their broader impact on health and disease.

In particular, the developing countries of Southeast Asia are undergoing simultaneous and rapid urban and agrarian transitions that threaten to disrupt some long-standing norms of governance (e.g. Lebel et al., 2006). Urbanization in developing countries has been referred to as a transformation, or an “urban transition” by planners, sociologists and development practitioners (Friedmann, 2005; Kessides, 2006; Saksena et al., 2014; Waibel, 2006;) rather than as a simple linear increase and concentration of populations in increasingly constrained spaces. This distinction points towards a definition of urbanization that includes two parallel processes: population concentration and the development of socio-physical infrastructure to manage the inevitable conflicts and problems associated with higher density living.

In general, beyond simply identifying high growth rates, the concept of transition implies a period of confusion and relative instability between states of social and environmental stability and predictability that need be empirically explored further. To date, however, analysis of the urban transition has focused on social factors rather than its interaction with the household-level built environment. Douglass (2000), for example, has identified five key changes and challenges of urban transitional regions important for planners and policy makers: 1) general governance issues; 2) the creation of livable cities through improved environmental management; 3) sustainable and long-term economies; 4) adequate attention to social justice and inequality; and 5) the tendency for uneven spatial development and rural neglect. In addition to these basic principles, others have focused on the growth of illegal settlements (Tang & Chung, 2002), the role of international trade (Pannell & Ma, 1997), as well as the political shifts that occur with such urbanization (Steck, 2006). In sum, most discuss the concept in general terms.

Simultaneous with this elaboration on the urban transition is the definition of an “agrarian transition” related to similar phenomena. Akram-Lodhi (2004) has defined the agrarian transition as four inter-related phenomena: 1) the differentiation of rural productive assets; 2) technological change that has led to the reorganization of rural production; 3) class-based agrarian accumulation; and 4) consequent new

political relationships in rural areas. To this set of factors driving rural social change, others have identified the importance of crop intensification and extensification, market integration, population mobility, new regulations, and a changing natural environment (deKoninck, 2004). While somewhat more specific than the literature on the urban transition, this body of work also speaks in broad terms.

Many of the broader implications of these simultaneous and related transitions remain largely unexplored in the context of health. Some work has touched on the empirical impacts of transitional environments on health. For example, research has shown that economic change has driven changes in the built environment that create new urban and peri-urban ecological health risks (Oliveira et al., 2004; Smith, 1997), and others show that migration to cities has simultaneously uprooted residents from local social networks and placed them into new forms of urban social organization that both threaten and improve access to basic health infrastructure such as water and sanitation access (Crane, 1994; Spencer, 2007).

Others have begun to theoretically explore the urban transition hypothesis in relation to specific diseases. Wilcox and Colwell (2005), Kapan et al. (2006), for example, have hypothesized that increasingly prevalent poultry avian influenza is one such EID that has roots in the confluence of biological, environmental, social and economic changes occurring at fast and slow rates of change within small areas, combined with the inability of social and governance institutions – adapted to known and prior health challenges – to respond to these new and unfamiliar effects on human health. These scholars' central premise is that human EID risks have arisen due to an inattention to the physical and social changes associated with urban and agrarian transitions that result in increased prevalence of disease among domesticated animals, which in turn is more easily transmitted to humans. Very few (e.g. Ferguson et al., 2005; Longini et al., 2005; Spencer, 2013), however, have empirically modeled the relationship between these combined forces and either human or animal EIDs.

5. The case of avian influenza in Vietnam

The case of Vietnam presents an excellent opportunity to test the theory that the precursors to human EID's – in this case, HPAI among poultry – are more likely to occur in targeted areas undergoing a transition from agrarian to urban ways of living. Longini et al. (2005) and Ferguson et al. (2005) separately modeled possible H5N1 (the scientific terminology for virus type in Vietnam) outbreaks among human populations, attempting to predict how a human HPAI pandemic might evolve in Thailand. As a starting point, their analysis used spatial units to predict how quickly and in which geographic directions an H5N1 pandemic would move. While their findings could not conclusively point to future outbreaks, the studies show promise for developing new spatial tools for understanding when a possible epidemic might become a pandemic beyond effective intervention, and thereby have targeted geographic implications for possible responses to a human avian influenza pandemic. Because of their focus on HPAI in humans, neither of these studies contribute significantly to an improved understanding of how and why H5N1 among poultry has evolved in the places it has. Spencer (2013) analysis of district level spatial units in Vietnam seeks to understand the origins of HPAI in poultry by creating “coherence” indices of micro-spaces in order to determine the association between HPAI poultry outbreaks and the urban transition. These measures also provide a methodological platform for estimating many different acute impacts of the urban transition.

The current paper follows these previous studies in its local spatial approach (in the form of neighborhoods for urban areas and villages in rural areas) to H5N1 in seeking to understand why poultry outbreaks have occurred where they have. To answer this question, we have assembled a range of demographic, infrastructural, and agricultural variables at the district- and commune-level that enable us to conduct multivariate logistic regression on a confidential set of national data on

H5N1 outbreaks at the commune and district level.

6. Data and methods

Documenting the relationship between general urbanization and HPAI in poultry can be done qualitatively (e.g. Finucane, Nghiem, et al., 2014) or quantitatively (e.g. Saksena et al., 2015); since one of our goals is to provide precise policy recommendations at a national level, we have used the latter approach. The data discussed here were made possible by National Science Foundation (grant # 0909410) and facilitated through close collaboration with Vietnam’s Ha Noi University of Agriculture. Vietnam has a strong, national-scale data collection and monitoring history that allows for a national-scale analysis of H5N1 outbreaks that includes extensive human-scale data agglomerated into spatial communities. For these two reasons, our empirical study of the socio-ecological factors of H5N1 emergence uses Vietnam as a case study. Moreover, we use multivariate logistic regression of spatial units of analysis as has been effectively used by planners in urban economics (e.g. Dowall, 1996) and urban public health (e.g. Weimann, Dai, & Oni, 2016).

Unlike an ordinary least squares regression, logistic regression can accurately assess the correlates of a binary variable of whether an outbreak occurred or not. A multivariate logistic regression (MLR) will produce a set of odds ratios that describe the likelihood of a binary event occurring. An odds ratio (OR) of 1 indicates that an independent variable (IV) has no detectable impact on the likelihood of an outbreak, while an OR of 0.30 means that for every full unit increase of the IV, there is a 70% reduction in the likelihood of that outbreak occurring. An OR of 1.30 means that there is a 30% increase in likelihood that the outbreak would occur.

The regression of secondary data by spatial aggregation requires the matching of multiple data sources in space and time, as well as careful attention to regional differences and aggregation scale issues that could influence data interpretation.

6.1. Spatial units of analysis

Administratively, Vietnam is comprised of small-scale governmental units mirrored in structure progressively from the local- to the national-level, and governed by “People’s Committees” at each level. The lowest administrative unit for which extensive data are collected is the commune level. These areas usually comprise approximately 10,000 residents, and the entire country is divided up into commune-level units. In general, several communes comprise a district governed by a separate People’s Committee with greater authority and resources, who in turn report to their provincial counterparts. Districts generally have populations that can reach over 150,000, and several of them comprise a province, of which Vietnam has roughly 60. In 2000, the base year for the geographies on which we matched demographic and agricultural data, Vietnam had 611 unique districts and approximately 10,000 unique communes. In this paper, we analyze the complete universe of both communes and districts.

Tables 1 and 2 show the descriptive statistics for each of the variables specified in our analysis at the District and at the Commune level.

6.2. Dependent variables (DV)

Working closely with the Ha Noi Agriculture University, we secured government-assembled records on HPAI outbreaks in Vietnam by commune and by district. While similar to outbreak data used in Spencer (2013), which allowed for only suggestive conclusions, these more systematic data come from a centrally-reported and maintained database rather than compiled through news reports. For our purposes, we used data that included H5N1 outbreaks that occurred during the two-year period 2004–2005, one of the most active periods of H5N1 outbreak in Vietnam. The data file we created from this source includes

Table 1
District-Level Descriptive Statistics of DV’s and IV’s.

	N	Mean	Median	Std. Deviation
Water Supply Coherence Index	662	0.4431	0.3987	0.28614
Sanitation Coherence Index	662	0.3429	0.2881	0.25000
Construction Materials Coherence Index	662	0.3090	0.3040	0.20146
Poultry density	662	5.2504	2.3027	6.75453
Modernization Index	662	0.2353	0.1978	0.19674
% Completed Secondary School	662	0.1306	0.1060	0.09232
% Completed College	662	0.0087	0.0080	0.00475
% Collective Sector Employment	662	0.2249	0.0076	0.32755
*Presence of HPAI Outbreak (2004–2005)	662	# of Districts with outbreaks 447		

Table 2
Commune-Level Descriptive Statistics of DV’s and IV’s.

	N	Mean	Median	Std. Deviation
Water Supply Coherence Index	10,301	0.4888	0.4020	0.27703
Sanitation Coherence Index	10,301	0.3804	0.338	0.25969
Construction Materials Coherence Index	10,301	0.3648	0.3685	0.20183
Poultry density	10,810	7.0698	3.2658	9.68501
Modernization Index	10,301	0.2353	0.1978	0.19674
% Completed Secondary School	10,373	0.1216	0.0897	0.10358
% Completed College	10,373	0.0084	0.0067	0.00708
% Collective Sector Employment	10,373	0.2865	0.0057	0.39172
*Presence of HPAI Outbreak (2004–2005)	10,810	# of Communes with outbreaks 2741		

information on the number of poultry “at risk,” number of “cases” of infected birds, number of poultry deaths due to infection, and number of birds destroyed as a preventative response by governmental authorities. Our data also show the district or commune in which an outbreak happened by year. In addition, it includes the number of infected people for the same periods, though we do not use this data in the current study because the numbers were insufficient for analysis.

From this data file, we created new district and commune variables that marked whether the given spatial unit had an outbreak or not by using the number of “cases” as our measure. Rather than rely on the raw numbers of poultry affected in each district or commune, we chose to assess the correlates of areas that *experienced* an outbreak rather than the number of infected birds as a result of the outbreak, following Pfeiffer, Minh, Martin, Epprecht, and Otte (2007), and most studies of HPAI (Gilbert et al., 2006; Gilbert et al., 2008; Loth, Gilbert, Osmani, Kalam, & Xiao, 2010; Loth et al., 2011; Martin et al., 2011). This choice is important because the number of poultry infected by the time an outbreak is identified may be as closely related to the disease management systems – post-outbreak - as they are to the factors giving rise to the outbreak in the first place, which is the subject of our empirical approach. These commune- and district-level variables, thus, allow us to isolate the spatial correlates of HPAI.

6.3. Independent variables (IV)

6.3.1. Coherence indices (Kuznets-shape development in communities)

Spencer (2013) developed a new methodology for estimating and measuring transitional spaces, and applied it to the issue of emerging infectious diseases in Vietnam. This method mathematically defines a set of indices of “settlement coherence” based on household-level infrastructure and amenities. In particular, the measure examined household-level building material, water supply, and sanitation systems to estimate the extent to which periurban neighborhoods displayed traditional, transitional, or modern characteristics. Detailed discussion of these coherence indices can be found in Spencer (2013), but, in sum,

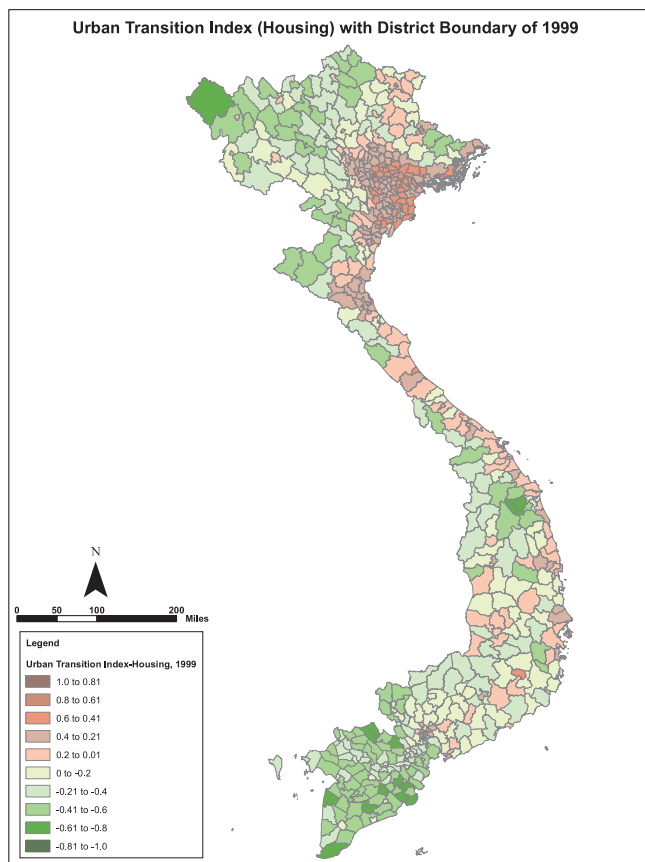


Fig. 2. District Coherence Index for Housing Construction Materials, 2006

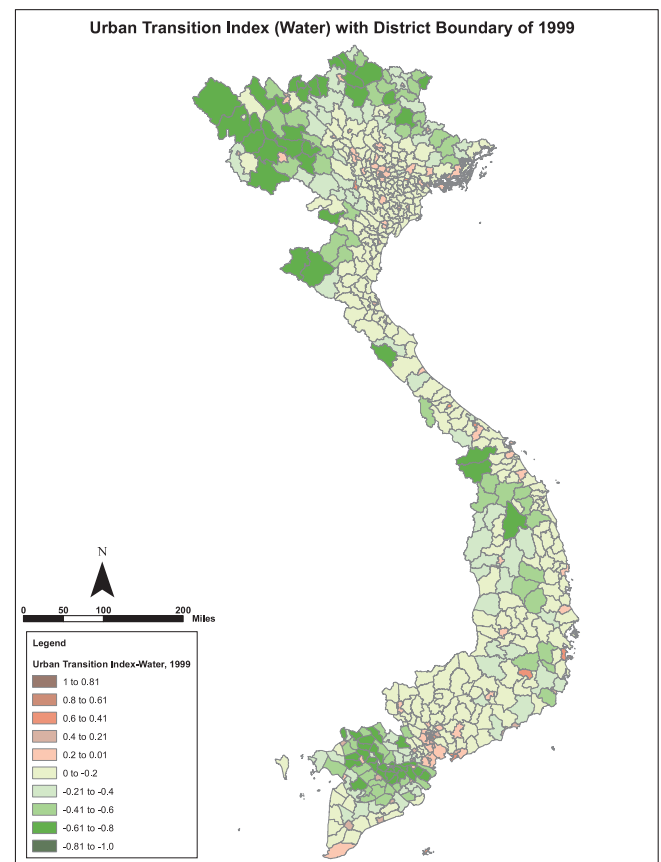


Fig. 3. District Coherence Index for Water Supply, 2006

the original scale from -1 to $+1$ measures the relative mix of four types of household features that are generally considered to be measures of increasing modernization. So, for example, the sanitation coherence measure equals -1 where all households in a given commune or district have no toilet (least modern), and a $+1$ where they all have a flush toilet (most modern). The sanitation coherence measure equals 0 , for example, where each of the four household technologies - no toilet, a pit latrine, a composting toilet, or a flush toilet - are 25% of the total. For our purposes here, where we use the variable in a regression model instead of displaying visual patterns, we take the absolute value of the coherence indices. Thus, the lowest-risk areas (both perfectly urban and perfectly rural) at both ends of this metric variable distribution are valued at 1, and highest risk ones at 0.

The original use of this method in Spencer (2013) was for commune- and district-level data from the 1999 Vietnam Census of Population and Housing. In this study, we update the methodology with the same coherence index variables, but taken from the 2006 Agricultural Census. To illustrate the geography of these household infrastructures, Figs. 2, 3, and 4 show the raw values (i.e. not the absolute values) of district level measures of urban transition.

There are certainly many other components of the risk associated with HPAI outbreaks.

6.3.2. Poultry spatial density

First and foremost, the presence of poultry is associated with HPAI outbreaks. Because of this, we used data on the number of chicken, ducks, and other poultry from the 2006 Agricultural Census at the district and commune level as a control variable. Using ArcGIS-generated area measures, we estimated poultry density in 2-dimensional geographic space, per kilometer.

6.3.3. Modernization Index (linear-shape development in communities):

The idea of a Kuznets-shaped urban transition is one way of conceiving of urbanization that follows a different trajectory than a simple, linear pathway of modernization. To account for this linear long-term trend of modernization, we developed a variable to track linear patterns of development that are distinct from the Kuznets coherence indices. Here, the numeric values of completely modern areas are very different from completely traditional ones, unlike for the coherence indices variables. This variable was defined as the percentage of households with the triad of most modern household infrastructure – flush toilets, tap water, and modern construction. Accounting for this linear trend, we further isolate the components of urbanization that are linear.

6.3.4. Percent Completed Secondary School and Completed College

In addition to poultry prevalence and modernization, there are certainly population education components of areal risk profiles. The public health risks associated with greater density of human activities can be mitigated – at least for a time – with good knowledge of hygienic practices such as hand-washing and safe food preparation, and in Vietnam they are known (To, Lee, Nam, Trinh, & Do, 2016), or suggested (Buccheri et al., 2007) to be correlated. These factors of disease risk are most consistent with the hypothesis that “wet markets” in Asia are one of the primary sources of HPAI outbreaks (Fournié et al., 2012). Thus, including the percent of the adult population with a secondary school education, as well as the percent of the population that has completed college should provide a good measure of background awareness of human sanitary issues regarding HPAI. Of course, our interest here is in poultry behavior that minimizes exposure to risk; however, in the absence of good poultry behavior variables, we hypothesize that a more educated community will show differences regarding their overall common-sense practices in keeping livestock and wild populations separated on the farm, and in wet markets.

Urban Transition Index (Sanitation) with District Boundary of 1999

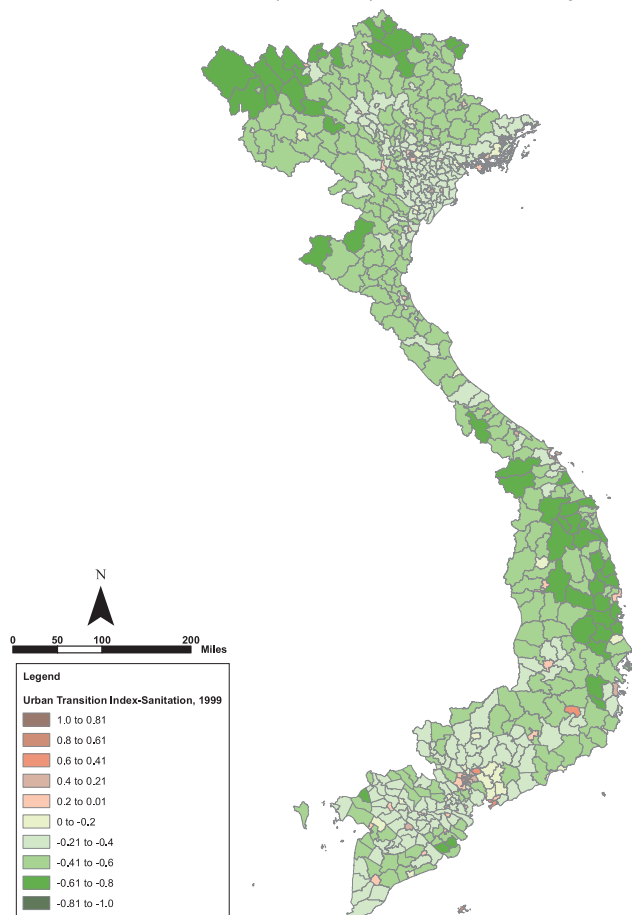


Fig. 4. District Coherence Index for Sanitation Technology, 2006

6.3.5. Percent collective sector employment

Talhelm et al. (2014) have demonstrated that the practice of rice agriculture and the use of work collectives have long-term results on how collective goods are locally achieved; that this form of work organization will result in positive collective action on subsequent community-level issues. Similarly, Carnap (2017) has outlined the debate using the language of “social capital,” but finds that such cooperative work structures do not cross over to achieve results outside of agriculture. Whatever the case, though, historic forms of agricultural work organization may affect a community’s capacity to act collectively in general. Thus, we include a proxy of collective sector employment to account for this influence.

As noted above, the extent of outbreak – i.e. how many birds catch the disease – can be a result of reactive public policies such as extermination campaigns as much as predisposition for the outbreak itself, and is therefore left out of our dependent variable. However, the extent to which a local area has a functional administrative structure and governing capacity is an important factor in all the socio-physical management responsibilities prior to the occurrence of an outbreak. This is especially relevant with regard to land use management. Thus, governance at the local level should be accounted for in our model. Given its Socialist history, Vietnam has a robust system of collectives that match the capacities of local government to implement policy among its population, although it varies significantly by region. This variable measures the percentage of people in the community who work in collective agriculture, and also serves as a proxy for the overall capacities of local government and related social organizations to minimize risk.

6.3.6. Unobserved variables (residuals and regional analysis)

Finally, there are certainly other variables that cannot be estimated using large datasets. Animal health programs, proximity to wild fowl, and other similarly unmeasured factors contribute to the risk profile of communes and districts. To address this issue, we ran the models including residual Z-scores and by regional and provincial dummy variables to even further isolate the coherence indices from other factors. We anticipate that the coherence indices will retain their magnitude of impact on the likelihood of outbreaks once these unobserved factors are accounted for. Thus, while these unobserved variables cannot be specifically named, their inclusion adds important factors that strengthen our conclusions, and help to confirm the relevance of our transitional coherence indices.

7. Limitations of the Model

Our analysis embodies many conventional challenges associated with statistical analysis, such as data entry errors and inaccurate record-keeping, for example. One of the strengths of our model is that our statistical model is not a sample, but the entire “population” of geographic units; thus, probability issues of confidence intervals and representativeness of a larger population of interest are minimal regarding spatial units. On the other hand, some of the population estimates within these units are 5% probability samples of the populations, thereby introducing some estimation error. Given that our measures of variance in the data cannot distinguish between sampling error in the process of sampling households and actual “population” variation associated with the data for spatial units, there is a certain amount of sampling error that we are unable to quantify.

A second category of limitations arises due to our use of secondary data sources not tailored specifically to our interests. First, while the primary concern of the field is human HPAI outbreaks, there are not enough detail and number of cases to conduct our analysis with confidence. Thus, our analysis centers on the precursor to human risk. Secondly, our model analyzes the markers of elevated outbreak risk, and one must be careful about inferring conclusions about direct causality of the various risk and protective factors, though this may be the ultimate objective. Finally, as our discussion will reveal, the model depends significantly on spatial scales.

8. Results

8.1. Coherence indices and HPAI outbreak

Tables 3 and 4 present the three coherence indices using the independent variables entered into the model sequentially as a step-wise regression. As predicted, as each coherence variable is complemented with new independent variables, the odds ratios for the indices become smaller in magnitude. As the model adds factors, the magnitude of the effect increases – i.e. the odds ratio becomes further distanced from the value of “1” for which there is no detectable difference in the odds of the dependent variable outcome based on the independent variable value. In other words, as the model becomes more sensitive, the same degree of coherence begins to shift away from equal odds to very much lower odds for the district analysis shown in Table 3. Thus, for water supply coherence, a district with complete coherence – either of the traditional kind or the modern kind – was 31.7% as likely as a district with complete incoherence – e.g. roughly one fourth of the households using each of the water supply technologies – to have an outbreak of HPAI in 2004–05. The figure was 29.4% for sanitation coherence, and 50.5% as likely for construction materials, although for construction materials we cannot be 95% sure that the value is not 100%, or equally, likely.

This phenomenon can also be observed in the commune analysis shown in Table 4. Communes of complete water supply coherence were 31.8% as likely as maximally incoherent ones to have had an outbreak;

Table 3
Odds Ratios of HPAI District Outbreaks, 2004–05 (95% confidence intervals in parentheses).

	Viet Nam Household Water Supply Coherence Index			Viet Nam Household Sanitation Coherence Index			Viet Nam Household Construction Materials Coherence Index		
Coherence Index	1.224 (0.522; 2.674)	0.405 (0.116; 0.966)	0.317 (0.105; 0.952)	0.410 (0.213; 1.095)	0.348 (0.173; 0.977)	0.294 (0.118; 0.735)	0.840 (0.335; 2.952)	0.293 (0.120; 1.346)	0.505 (0.140; 1.824)
Poultry density	1.274 (1.192; 1.360)	1.227 (1.144; 1.304)	1.275 (1.183; 1.374)	1.243 (1.172; 1.328)	1.198 (1.131; 1.281)	1.261 (1.174; 1.354)	1.266 (1.184; 1.348)	1.244 (1.162; 1.321)	1.284 (1.194; 1.381)
Modernization Index		20.379 (5.415; 171.732)	34.665 (5.545; 216.689)		13.783 (3.994; 45.928)	15.512 (3.996; 60.206)		18.359 (5.744; 59.507)	18.641 (5.060; 68.676)
% Completed Secondary School			2.773 (0.016; 469.622)			7.769 (0.043; 1413.863)			4.450 (0.032; 615.941)
% Completed College			0.000 (0.000; 0.000)			0.000 (0.000; 0.000)			0.000 (0.000; 0.001)
% Collective Sector Employment			0.656 (0.310; 1.389)			0.501 (0.235; 1.069)			0.650 (0.305; 1.387)
R2 (Cox & Snell)	0.166	0.184	0.204	0.158	0.183	0.207	0.154	0.189	0.202
R2 (Nagelkerke)	0.232	0.258	0.286	0.226	0.261	0.295	0.218	0.268	0.287

communes with complete coherence of sanitation technology were 44.9% as likely to have had an outbreak; and those with complete coherence of construction materials were 40.8% as likely. When seen through the lens of the district, the sanitation coherence appears to be associated with the least risk of HPAI outbreak (29.4%). Similarly, when seen through the spatial lens of the commune, sanitation coherence is the most associated with reduced risk (44.9%), though all three coherence measures do show reduced risk of HPAI.

In addition to the change in magnitude of the odds ratios, each progressive model increases the explanatory power (R-squared value), explaining roughly 20–30% of differences in the odds of outbreak for the district analysis, and a much lower 5–8% of these differences when the issue is seen through the commune level of analysis.

As with any spatial analysis, the choice of geographic units of aggregation has important implications. For this reason, we present here the analysis at both levels, finding that the same pattern exists regardless of scale. Of the six coefficients generated (3 variables at each geographic scale), all showed at least a 50% less likelihood of outbreak in perfectly coherent areas when compared to areas that are maximally incoherent. Interestingly, the overall model fit at the district scale was better than at the commune level. We believe this difference to be due

to the fact that each district includes at least one relatively urbanized area, while some communes may be almost all rural. Thus, almost every district contains the full range of possibilities for coherence index values, while communes are much less likely to, and this distinction likely explains why the model fits much better for districts than for communes.

Overall, though, our findings that household level coherence of services and infrastructure was associated with lower risk of HPAI outbreaks in 2004–05 is consistent and robust across spatial scales.

Importantly, Tables 3 and 4 show that the effect of poultry density – as the primary factor of outbreaks – remains remarkably consistent at about 1.20 across the three DV’s and 2 spatial scales. The range of social and community factors added in sequence affect the magnitude of the coherence indices, while the poultry density magnitude remains relatively unchanged. This fact supports our model by confirming that coherence indices are related to other social/human factors of community-scale measures, and suggests that our model generally and accurately estimates the human and social aspects of HPAI outbreaks, with the household infrastructure landscape as a distinct measure of those social aspects.

Some of the other IV’s showed surprising correlation with outbreaks

Table 4
Odds Ratios of HPAI Commune Outbreaks, 2004–05 (95% confidence intervals in parentheses).

	Viet Nam Household Water Supply Coherence Index			Viet Nam Household Sanitation Coherence Index			Viet Nam Household Construction Materials Coherence Index		
Coherence Index	0.981 (0.783; 1.229)	0.369 (0.287; 0.475)	0.318 (0.245; 0.413)	0.631 (0.506; 0.787)	0.412 (0.325; 0.516)	0.449 (0.354; 0.569)	0.615 (0.482; 0.785)	0.283 (0.228; 0.384)	0.408 (0.307; 0.544)
Poultry density	1.030 (1.025; 1.035)	1.017 (1.012; 1.022)	1.030 (1.024; 1.037)	1.026 (1.021; 1.031)	1.016 (1.011; 1.021)	1.027 (1.021; 1.033)	1.034 (1.029; 1.040)	1.030 (1.025; 1.036)	1.036 (1.030; 1.041)
Modernization Index		18.558 (12.712; 25.964)	37.996 (25.643; 56.299)		8.333 (6.249; 10.560)	12.456 (9.413; 16.481)		8.676 (6.525; 10.695)	12.091 (9.255; 15.795)
% Completed Secondary School			0.038 (0.012; 0.121)			0.063 (0.022; 0.183)			0.057 (0.021; 0.157)
% Completed College			444.287 (0.001; 234920680.465)			76.966 (0.000; 19859819.189)			7226.016 (0.050; 1045251909.612)
% Collective Sector Employment			0.510 (0.440; 0.592)			0.565 (0.494; 0.647)			0.680 (0.590; 0.784)
R2 (Cox & Snell)	0.015	0.043	0.059	0.015	0.041	0.054	0.018	0.046	0.055
R2 (Nagelkerke)	0.022	0.064	0.087	0.022	0.059	0.078	0.026	0.067	0.079

Table 5
Construction Materials Odds Ratios of HPAI District Outbreak 2004–05, by Region and Province Dummy.

Includes Provincial Dummy Variable	Provincial Dummy + Z-Scores									
	Red River Delta	North East	North West	North Central Coast	South Central Coast	Central Highland	South East South	Mekong Delta	Viet Nam	Viet Nam (Z-scores)
Building Materials Coherence 2006	754.666	0.211	0.003	0.833	0.000	0.053	2.423	.	0.313	0.002
PoultryDensity, 2006	1.317	1.122	0.546	1.219	3.588	1.215	0.723	1.442E37	1.245	3.061
Modernization Index 2006	0.007	25.913	1.657E11	0.898	114.894	0.000	0.785	0.000	3.692	578.685
Percent Completed Secondary School (15 +)1999	5.673E9	64.536	1.017E37	5.657E9	1.446E20	3.009E9	0.000	.	5121.214	4.445E26
Percent Completed College 1999 (15 +)	0.000	0.000	0.000	0.000	0.000	2.227E104	1.436E67	.	0.000	0.000
Percent Collective Sector Employment (15 +)	6.413	2.421	44.302	6.265	21.384	718.168	0.000	0.000	6.314	396555.665
Constant	6438707.793	95.034 ^a	2.570	0.657	0.000	0.062	8.378E9	0.000	1.164E9	4.393E8
- 2 Log likelihood	26.577 ^a	0.366	30.741 ^a	75.925 ^a	23.260 ^a	49.621 ^a	46.316 ^a	0.000	422.980 ^a	.000 ^a
R Square (Cox & Snell)	0.210	0.366	0.405	0.344	0.638	0.351	0.433	0.000	0.427	0.705
R Square (Nagelkerke)	0.545	0.502	0.543	0.465	0.851	0.474	0.600	0.000	0.606	1.00

Table 6
Sanitation Odds Ratios of HPAI District Outbreak 2004–05, by Region and Province Dummy.

Includes Provincial Dummy Variable	Provincial Dummy + Z-Scores									
	Red River Delta	North East	North West	North Central Coast	South Central Coast	Central Highland	South East South	Mekong Delta	Viet Nam	Viet Nam (Z-scores)
Sanitation Coherence 2006	0.046	0.043	0.002	0.002	0.094	0.257	9.289	0.003	0.063	0.000
PoultryDensity, 2006	1.199	1.098	0.368	1.193	2.143	1.144	0.672	2.016	1.217	2.732
Modernization Index 2006	3.849	0.824	4392.022	1.610	3.002	0.000	23.733	1.581	4.200	4296.285
Percent Completed Secondary School (15 +)1999	40567.006	18512.174	1.085E37	4.136E8	2523938.196	8.017E9	0.000	0.000	17968.853	1.096E26
Percent Completed College 1999 (15 +)	0.000	0.000	0.000	0.000	0.000	4.960E53	4.536E19	1.304E202	0.000	0.000
Percent Collective Sector Employment (15 +)	3.631	1.826	14.846	3.802	4.240	280.087	0.073	0.000	3.589	3718.510
Constant	1.795E9	2.699	271.838	0.916	0.000	0.117	8.606E8	0.000	1.645E9	3.725E9
- 2 Log likelihood	406.409 ^a	91.020 ^a	28.662 ^a	68.495 ^a	28.135 ^a	50.022 ^a	38.961 ^a	18.722 ^a	388.526 ^a	.000 ^a
R Square (Cox & Snell)	0.442	0.379	0.369	0.391	0.594	0.347	0.468	0.215	0.439	0.701
R Square (Nagelkerke)	0.627	0.522	0.492	0.530	0.792	0.468	0.656	0.653	0.626	1.00

Table 7
Water Supply Odds Ratios of HPAI District Outbreak 2004–05, by Region and Province Dummy.

Includes Provincial Dummy Variable	Provincial Dummy + Z-Scores									
	Red River Delta	North East	North West	North Central Coast	South Central Coast	Central Highland	South East South	Mekong Delta	Viet Nam	Viet Nam (Z-scores)
Water Coherence 2006	0.727	0.066	0.112	0.028	23386.159	0.061	0.001	0.315	0.000	0.000
PoultryDensity, 2006	1.277	1.107	0.630	1.121	1.856	1.250	0.769	1.238	3.157	1.238
Modernization Index 2006	0.033	110.075	283168.440	961.998	0.000	0.000	377682.802	9.704	804458.318	804458.318
Percent Completed Secondary School (15+)1999	2.194E8	36.546	6.796E33	1.537E10	75917.065	6.576E8	0.013	5477.313	1.469E27	1.469E27
Percent Completed College 1999 (15+)	0.000	0.000	0.000	0.000	0.000	8.347E83	0.000	0.000	0.000	0.000
Percent Collective Sector Employment (15+)	5.614	1.996	13.410	9.139	9.823	721.941	1.342E44	7.431	1362672.977	1362672.977
Constant	1.768E8	0.971	1.159	0.333	0.000	0.111	1.456E9	1.456E9	3.939E9	3.939E9
-2 Log likelihood	26.132 ^a	92.450 ^a	33.612 ^a	68.307 ^a	29.379 ^a	49.703 ^a	28.560 ^a	387.238 ^a	.000 ^a	.000 ^a
R Square (Cox & Snell)	0.228	0.378	0.356	0.380	0.583	0.350	0.522	0.442	0.714	0.714
R Square (Nagelkerke)	0.534	0.518	0.477	0.512	0.779	0.473	0.718	0.619	1.00	1.00

Table 8
Construction Materials Odds Ratios of HPAI Commune Outbreak 2004–05, by Region and Province Dummy.

Includes Provincial Dummy Variable	Provincial Dummy + Z-Scores									
	Red River Delta	North East	North West	North Central Coast	South Central Coast	Central Highland	South East South	Mekong Delta	Viet Nam	Viet Nam (Z-scores)
Building Materials Coherence 2006	3.939	0.626	0.701	1.050	0.262	0.940	1.173	0.461	0.872	0.310
Poultry Density, 2006	1.019	1.009	1.122	1.008	1.098	1.026	1.045	1.025	1.021	1.167
Modernization Index 2006	1.359	1.980	696.241	3.578	8.757	2.704	0.361	0.376	2.507	631.862
Percent Completed Secondary School (15+)1999	0.268	10.021	2.715	263.131	0.132	6.148	4.646	2.524	8.949	335809.923
Percent Completed College 1999 (15+)	0.001	0.281	0.001	0.000	5.044E11	9.471E47	3.944E7	164.666	0.007	0.000
Percent Collective Sector Employment (15+)	0.934	1.295	3.181	2.984	2.175	7.796	24.956	1.959	1.889	68.100
Constant	0.235	0.185	0.006	0.087	0.000	0.010	0.329	1.759	0.701	0.116
-2 Log likelihood	2364.179 ^a	1631.836 ^a	298.118 ^a	1165.506 ^a	571.304 ^a	367.750 ^a	503.543 ^a	1329.838 ^a	8364.298 ^a	.000 ^a
R Square (Cox & Snell)	0.107	0.114	0.126	0.088	0.239	0.207	0.192	0.252	0.258	0.687
R Square (Nagelkerke)	0.148	0.188	0.262	0.165	0.373	0.354	0.309	0.350	0.376	1.00

Table 9
Sanitation Odds Ratios of HPAI Commune Outbreak 2004–05, by Region and Province Dummy.

Includes Provincial Dummy Variable	Provincial Dummy + Z-Scores									
	Red River Delta	North East	North West	North Central Coast	South Central Coast	Central Highland	South East South	Mekong Delta	Viet Nam (Z-scores)	
Sanitation Coherence 2006	1.955	0.436	0.189	0.653	0.861	0.241	1.043	1.089	0.701	0.165
Poultry Density, 2006	1.017	1.008	1.054	1.004	1.092	1.018	1.044	1.029	1.018	1.139
Modernization Index 2006	1.563	1.503	384.296	4.565	6.882	27.482	0.483	0.437	2.966	1373.603
Percent Completed Secondary School (15+)1999	0.254	8.896	3.052	312.335	0.051	3.072	0.778	2.127	10.440	901998.770
Percent Completed College 1999 (15+)	0.003	2.266	0.035	0.000	1.586E14	4.655E59	1.125E19	600311.190	0.003	0.000
Percent Collective Sector Employment (15+)	0.953	1.166	3.062	2.782	1.986	6.765	32.320	2.147	1.671	37.177
Constant	0.389	0.230	0.011	0.093	0.000	0.010	0.282	1.285	0.694	0.099
- 2 Log likelihood	2291.429 ^a	1548.936 ^a	259.813 ^a	1155.902 ^a	543.477 ^a	319.301 ^a	458.175 ^a	1322.533 ^a	8033.934 ^a	.000 ^a
R Square (Cox & Snell)	0.109	0.119	0.146	0.090	0.230	0.241	0.184	0.253	0.260	0.693
R Square (Nagelkerke)	0.151	0.194	0.289	0.16775	0.353	0.407	0.296	0.351	0.376	1.00

Table 10
Water Supply Odds Ratios of HPAI Commune Outbreak 2004–05, by Region and Province Dummy.

Includes Provincial Dummy Variable	Provincial Dummy + Z-Scores									
	Red River Delta	North East	North West	North Central Coast	South Central Coast	Central Highland	South East South	Mekong Delta	Viet Nam (Z-scores)	
Water Coherence 2006	0.450	1.707	0.415	0.438	0.715	0.903	0.909	1.334	0.743	0.136
Poultry Density, 2006	1.023	1.006	1.090	1.013	1.081	0.989	1.008	1.018	1.019	1.144
Modernization Index 2006	2.760	1.203	6578.951	8.282	18.137	8.825	0.601	0.664	3.653	4849.112
Percent Completed Secondary School (15+)1999	1.650	10.690	1.331	19.857	0.035	15.972	0.052	1.158	9.427	854357.508
Percent Completed College 1999 (15+)	0.000	111.026	5170.766	0.004	6.705E11	3.980E44	9.770E30	302.205	0.625	0.002
Percent Collective Sector Employment (15+)	0.888	1.290	3.039	2.811	2.325	8.548	39.355	2.285	1.808	45.452
Constant	0.427	0.123	0.004	0.118	0.000	0.010	0.296	1.156	0.929	1.678
- 2 Log likelihood	1777.354 ^a	1582.676 ^a	286.368 ^a	1030.213 ^a	484.953 ^a	359.102 ^a	322.298 ^a	1090.983 ^a	7042.713 ^a	.000 ^a
R Square (Cox & Snell)	0.131	0.113	0.129	0.084	0.211	0.212	0.240	0.259	0.265	0.680
R Square (Nagelkerke)	0.183	0.186	0.269	0.161	0.345	0.360	0.384	0.361	0.390	1.00

that we discuss below under a more regional approach, given that education and work collectives vary significantly in Vietnam by region.

9. Regional differences

Tables 5 through 10 further refine our analysis by accounting for regional differences at two higher spatial scales. Given that Vietnam is comprised of several different socio-ecological regions, and that the capacities of each province surely affect the reporting of outbreaks and the various intangibles of EID prevalence, we applied a number of additional tests to our data. First, we applied the basic model to each of the Vietnamese-General Statistics Office-defined 8 socio-ecological regions that some use to assess the context of public health and epidemics in Vietnam (e.g. Bui et al., 2011) that range from five to eleven provinces each, and added a dummy variable to the model to represent each of the provinces included in the model. We anticipated that these variations would account for a range of regional environmental and cultural differences and allow us to further isolate our coherence measures. The higher R-squared values for each of these sub-models confirms that we were able to effectively improve the model's accuracy, but it is also important to note that their inclusion did not alter the basic findings.

As a final effort to isolate the coherence indices, we included a Z-score residual variable in the model for the whole country, as well as a provincial dummy variable for each of the provinces to capture province-specific differences. Accounting for any unknown and unnamed pattern in the data in this way, we further isolated the coherence indices and improved the fit of the model, as shown by the increase of Cox & Snell R-squared measures for both scales to about 70%.

Assessing results following these model adjustments, shows interesting findings on our range of variables. First, in terms of the coherence indices, all three showed significantly less likelihood of outbreak at the district level, ranging from 31.3% and 31.5% respectively for construction materials and water supply, to 6.3% for sanitation. These coefficients approximately doubled for the commune analysis, other than for sanitation. We believe that this is likely the result of districts showing greater variation in sanitation coherence due to the universal presence of larger towns at this geographic scale. Thus, one of our most important findings is that, taken together, results suggest that because sanitation is the last of the three infrastructures that is implemented consistently in rural areas, that it may in fact be the best predictor of future poultry HPAI outbreaks – and perhaps the most protective of the three coherence measures tested.

Progressing down the tables, the linear modernization index that measures increasing household-level development independent of the Kuznets transitional risks shows consistently elevated HPAI risk, other estimated factors equal. As a strict measure of household wealth increase, this measure is consistent with the idea that household scale modernization reflects a growing economy likely associated with intensified livestock production, as has been the case in China (e.g. Bai et al., 2018), that overall elevates risk. We interpret this phenomenon as likely paired with similar results of the secondary education coefficients. While our original hypothesis was that secondary education would be associated with hand-washing and protection from HPAI, the results do imply that this measure may be dominated by its role in approximating rapid – and largely unmitigated - economic growth. In other words, without an explicit measure of increasingly modern economic opportunities, both household modernization and secondary education serve as proxies for the household wealth accumulation and individual human capital growth, respectively, both of which are linear, and measures of rapid economic development even though they may have some negative externalities. This explanation is much more consistent with our other findings than the explanation that these variables are directly related to HPAI risk. This is not to say that hand-washing is unimportant regarding HPAI risk, but that the positive effects are drowned out by education's function as a proxy for economic

development. Importantly, these findings suggest that HPAI risk in Vietnam is a part of the rapid development process, not necessarily something that is unexpected.

As described earlier, our hypothesis argues that prior collective action – as represented by both local government administrative capacity, as well as a more socially embedded culture of collective work – on one issue may influence current and future collective action on other issues. In almost every run of our model, collective sector employment correlated with greater HPAI risk. This finding echoes some of the critiques of social capital that such networks can be systematically dysfunctional under certain circumstances – a kind of “negative” social capital associated with work collectives and historical local administrative practices (Portes, 2014). Our results do clearly show a negative impact of the variable, and is best interpreted as suggesting that work collectives and the local administrative capacities that they represent may embody historical practices and habits that elevate risk of HPAI outbreak. Further investigation of this result is warranted, but some initial illustrations of relevant hypotheses might include that collectives are less willing to self-regulate, or that they embody institutional and habitual resistance to changes in livestock, agricultural, and other practices.

Overall, the regional results show a lot of variation based on the region of the country, especially when the district scale is used as the lens of analysis. Most of the eight sub-regions show odds ratios consistent with the national results, with a few exceptions. As shown in Table 5, the construction materials odds ratio for the Red River Delta region shows over 70,000 increased odds for districts with coherent construction materials composition to have experienced an outbreak, and the Southeast South region shows a 242% increased odds of having an outbreak with full coherence. These very high figures are in striking opposition to other regions of the country, with much lower odds ratios, all of which are less than 1. On the other hand, Table 6 shows the odds ratio for the Red River Delta regarding sanitation coherence is less than 5% likelihood of a sanitation-coherent district having an outbreak compared to a fully incoherent one. The South Southeast remains at elevated HPAI likelihood with greater coherence. There is a similar outlier region for the water supply coherence measure, the South Central Coast, when compared to the other regions in the country which generally have very low outbreak likelihoods for water supply-coherent districts compared to others. Here, results show a vastly increased likelihood of outbreak with coherent water supplies (23,386), even as the control variables show no particular divergence from the values of the other regions. Thus, there is clearly a case of outlying Coherence Index values across the three measures that needs to be explained.

In sum, and taken as a whole by district, the Red River Delta and the South Southeast regions are much more likely for construction materials-coherent districts to have outbreaks, and the South Central Coast is much more likely to have water supply-coherent districts have outbreaks. The magnitude of these outliers suggests that there is some important influence affecting these regions, and it is interesting to point out that these regions are the homes to the four largest cities in Vietnam: Ha Noi (7,216,000 population) and Hai Phong (1,763,000 population) lie on opposite ends of the Red River Delta, Ho Chi Minh City (8,146,300 population) is the center of the South Southeast, and Da Nang (1,328,000) is located in the northern part of the South Central Coast. Importantly, the population densities for these cities, respectively, are 2,170, 1,155, 2,170, and 1,033. Interestingly, the next largest city, Can Tho, has a population almost identical to Da Nang's, but the density is only 885 per square kilometer (all calculations based on 2015 figures, as described in General Statistics Office of Vietnam, 2015).

Thus, it seems that the size and density of Vietnam's four most populous cities may be the origins of the outlying characteristics for the 3 coherence indices presented at the district scale. While these outlier results for the coherence indices may be simply the result of the urban scale, these are also major trading ports for agricultural and livestock products, as well as local governments with significantly greater local

governmental autonomy granted by their classification as within the two top tiers of urban governmental authority in Vietnam. Thus, when taken at the district level, it appears that household infrastructure coherence is not a good predictor of HPAI outbreaks where there is the highest level of urbanization and managed development. This hypothesis explaining these outliers is consistent with Spencer (2013) results, which found that coherence indices correlated with the middle values of coherence, and therefore the cases of completely agrarian and completely urban development. What remains unclear from these regional findings, however, is whether the cause of this lack of fit in the developed urban areas is the result of the levels of economic activities related to poultry consumption, *trans*-shipment, and other secular trends, or whether the result of large, unified planning districts under control of a single water supply authority, sewer system, or master plan. One way to think about this question is whether the lack of fit results from greater poultry-related activity that elevates risk, or lesser capacities of the risk-reduction infrastructures. An examination of the findings at the commune level may shed some light on this question.

In principle, city-wide infrastructure systems are policies that establish uniform standards of service across municipal service areas, and therefore should show little variation across the districts and communes within the municipalities. On the other hand, poultry-related activities have no unified service-type of characteristics, so one would expect much more variation across the municipality that is the result of poultry-oriented activities. Thus, if the risk-reduction capacities were the reason why the coherence indices fit less well in these cities, then one would expect to find similar results when examined at the commune level; if the commune results differ significantly in magnitude and/or direction, it is more likely that the poultry-related activities is the reason why the model does not fit well in these areas.

When the regional analysis is conducted at the commune spatial level, there are few of these vast variations in odds ratio across socio-ecologic areas. As with the district analysis, Table 8 shows elevated risk for coherence communes in the Red River Delta and the South Southeast regions (3.939 and 1.173 respectively), but Table 10 shows the South Central region with an odds ratio below 1 (0.715), which differs not only in magnitude, but direction as well, from the positive outlier seen in Table 7. In sum, while two of the outliers identified in the district analysis remain strongly positive, they are no longer outliers. On the other hand, the greatest outlier – the South Central Coast’s odds ratio for water supplies – turns into a somewhat negative, less risky, case. While not conclusive, these changes to the results when the smaller geographic scale is used does suggest that variation in the risk-producing poultry-related activities may be a stronger driver in large urban areas than variation in the risk-protecting infrastructures.

In sum, the fact that the Red River Delta, the South Southeast, and the South Central Coast areas show different patterns of the associated risk of outbreak with the coherence measures is most likely due to the fact that these represent the centers of Vietnam’s megacities. Because of this, the district level in a megacity region is likely to represent a very different set of daily relationships among households than it is in a more remote area where agricultural practices are major aspects of daily life. Consistent with this interpretation, the odds ratios for the Red River Delta and the South Southeast at the commune level are much more in line with the other regions’ results. One simple way to think about these outliers is that a district in the mega-region of Ho Chi Minh City is more like a city than it is like a district. On the other hand, any given commune in the Ho Chi Minh City region is probably more like a commune in one of the smaller and more remote regions. Overall, this interpretation suggests that further research must be done if the coherence index approach may be appropriate for fully urbanized areas.

10. Discussion and concluding thoughts

Despite the numerous descriptive studies of both the urban

transition and of EID’s, there has been little empirical work done to document the extent of both of these phenomena, and even less that attempts to test the hypothesis that the precursor to human EIDs, increased disease prevalence among domesticated animals, are a predictable outcome of the urban transition. Using a previously-tested measure of “coherence,” this study examines the independent association between the outbreaks of HPAI in Vietnam and a set of coherence indices that measure nonlinear urban transitional dynamics.

The resulting logistic analysis strongly confirms what others have hypothesized more generally about emerging infectious diseases – that they are predictable, nonlinear results of gradually transitioning environments (Wilcox & Colwell, 2005). Our study used household level infrastructures such as water supply, sanitation technology, and construction materials to explain where HPAI outbreaks occurred in Vietnam and where they did not, independent of other factors. On a practical level, such findings can help determine what kinds of household infrastructure landscape changes at the community scale are markers of EID risk.

Overall, the paper makes two substantive contributions. First, theoretically defining and estimating a Kuznets curve for urbanization and human settlement is a key step towards developing a valid theoretical and multivariate – as distinguished from Spencer (2013) – model for understanding the household infrastructure landscape transition contributors to the emergence of new infectious diseases. More precisely, it seeks to understand the rapid emergence of formerly rare diseases among animals, which in turn presents dire risks for human populations. While our case examines HPAI in the context of Vietnam, the concept and methodology is easily adapted to other concerns ranging from Ebola to the re-emergence of dengue fever. Given the global importance of our rapidly expanding urban landscapes and ecologies, this approach towards the study of urbanization – and its importance for understanding new health risks – has broad applicability. Moreover, since urban expansion is largely the result of complex individual and societal decisions, planning and policy has a central role to play. In fact, the types and gaps in urban and regional planning may not just be the solutions to a growing problem of EID’s, but in fact they may be their cause as well. Before such questions can be answered using the coherence indices defined in this paper, however, a better understanding of how the model must be adapted to highly urbanized areas must be developed through future studies.

Second, our empirical investigation provides quantified evidence on built environment household characteristics as correlates of HPAI outbreaks in Vietnam. In doing so, it stands to provide planners and policy makers with a set of heretofore unavailable spatial identification tools. One approach following from the analysis would be increased surveillance for HPAI in communities of high “incoherence” as measured by the most robust variables. For this policy implication, our finding that HPAI risk is most elastic and protective with respect to unit changes in sanitation coherence is important. Our research suggests, for example, that targeting those districts with the greatest disparities regarding the mix of sanitation types – i.e. where sanitation coherence measures are at, or close to zero – would yield the greatest payoffs, even though focusing on water supply characteristics and construction materials would also be helpful. Thus, for example, proactively monitoring poultry flocks in these areas of great diversity in sanitation infrastructure would mean placing monitors there so as to make epidemic and pandemic outbreaks much more quickly identified than is currently possible. Such a directed planning intervention, as opposed to one that spread efforts out across the country with less intensive observation, would lead to improved surveillance results.

Beyond faster epidemic identification timelines, there may be some more proactive implications, although we describe these with less confidence. If, in fact, the mix of sanitation type (or water supply and construction materials types) is *causally* related to outbreaks – a relationship we were unable to explicitly test here – in addition to being simply markers of outbreak risk, then health planners would make

additional efforts to prioritize efforts to standardize community sanitation infrastructures, whether it be on a low tech option like a pit latrine, or a high end one like flush toilets.

Overall, our main point in this study is to show that the important influence of development and economic growth with respect to HPAI is the coherence and standardization of household-scale infrastructures rather than their levels of modern technology in an absolute sense. Further investigation should more directly measure this potentially causal relationship between our coherence measures and outbreaks. Finally, our results also indicated that planners and policy makers might usefully investigate the role that work collectives may play in heightening the risk of outbreak.

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References

- Akram-Lodhi, A. H. (2004). Are 'landlords taking back the land'? an essay on the agrarian transition in vietnam. *European Journal of Development Research*, 16(4), 757–789. <https://doi.org/10.1080/09578810412331332622>.
- Bai, Z., Ma, W., Ma, L., Velthof, G. L., Wei, Z., Havlik, P., & Zhang, F. (2018). China's livestock transition: Driving forces, impacts, and consequences. *Science Advances*, 4(7), <https://doi.org/10.1126/sciadv.aar8534>.
- Berke, P. R., & Campanella, T. (2006). Planning for postdisaster resiliency. *The Annals of the American Academy of Political and Social Science*, 604(1), 192–207. <https://doi.org/10.1177/0002716205285533>.
- Buccheri, C., Casuccio, A., Giammanco, S., Giammanco, M., La Guardia, M., & Mammina, C. (2007). Food safety in hospital: Knowledge, attitudes and practices of nursing staff of two hospitals in sicily, italy. *BMC Health Services Research*, 7(45), <https://doi.org/10.1186/1472-6963-7-45>.
- Bui, H., Clements, A. C. A., Nguyen, Q. T., Nguyen, M. H., Le, X. H., Hay, S. L., & Horby, P. (2011). Social and environmental determinants of malaria in space and time in vietnam. *International Journal of Parasitology*, 41(1), 109–116. <https://doi.org/10.1016/j.ijpara.2010.08.005>.
- Burby, R. J., Beatley, T., Berke, P. R., Deyle, R. E., French, S. P., Godschalk, D., & Platt, R. H. (1999). Unleashing the power of planning to create disaster-resistant communities. *Journal of the American Planning Association*, 65(3), 247–258. <https://doi.org/10.1080/01944369908976055>.
- Carnap, T. v. (2017). Irrigation as a historical determinant of social capital in india? A large-scale survey analysis. *World Development*, 95, 316–333. <https://doi.org/10.1016/j.worlddev.2017.02.035>.
- Crane, R. (1994). Water markets, market reform and the urban poor: Results from jakarta, indonesia. *World Development*, 22, 71–83. [https://doi.org/10.1016/0305-750X\(94\)90169-4](https://doi.org/10.1016/0305-750X(94)90169-4).
- De Koninck, R. (2004). The challenges of the agrarian transition in southeast asia. *Labour, Capital and Society*, 37(1/2), 285–288.
- Douglass, M. (2000). Mega-urban regions and world city formation: Globalisation, the economic crisis and urban policy issues in pacific asia. *Urban Studies*, 37(12), 2315–2335. <https://doi.org/10.1080/00420980020002823>.
- Dowall, D. (1996). An evaluation of california's enterprise zone programs. *Economic Development Quarterly*, 10(4), 352–368. <https://doi.org/10.1177/089124249601000405>.
- Feare, C. J. (2007). The role of wild birds in the spread of HPAI H5N1. *Avian Diseases*, 51(1), 440–447. <https://doi.org/10.1637/7575-040106R1.1>.
- Ferguson, N. M., Cummings, D. A. T., Cauchemez, S., Fraser, C., Riley, S., Meeyai, A., & Burke, D. S. (2005). Strategies for containing an emerging influenza pandemic in southeast asia. *Nature*, 437, 209–214. <https://doi.org/10.1038/nature04017>.
- Finucane, M. L., Fox, J., Saksena, S., & Spencer, J. H. (2014). A conceptual framework for analyzing social-ecological models of emerging infectious diseases. In M. J. Manfredi, J. J. Vaske, A. Rechkemmer, & E. A. Duke (Eds.). *Understanding society and natural resources: Forging new strands of integration across the social sciences* (pp. 93–109). New York: Springer, Dordrecht. https://doi.org/10.1007/978-94-017-8959-2_5.
- Finucane, M. L., Nghiem, T., Saksena, S., Nguyen, L., Fox, J., Spencer, J. H., & Thau, T. D. (2014). An exploration of how perceptions of the risk of avian influenza in poultry relate to urbanization in vietnam. *Ecohealth*, 11(1), 73–82. <https://doi.org/10.1007/s10393-014-0906-2>.
- Fournié, G., Guitian, J., Desvieux, S., Mangtani, P., Ly, S., Cong, V. C., & Ghani, A. C. (2012). Identifying live bird markets with the potential to act as reservoirs of avian influenza A (H5N1) virus: A survey in northern vietnam and cambodia. *Plos One*, 7(6), <https://doi.org/10.1371/journal.pone.0037986>.
- Frank, L., & Engelke, P. (2000). *How land use and transportation systems impact public health: A literature review of the relationship between physical activity and built form*. Georgia Institute of Technology and Center for Disease Control Retrieved from <https://www.cdc.gov/nccddp/dnpa/pdf/aces-workingpaper1.pdf>.
- Friedmann, J. (2005). *China's urban transition*. Minneapolis, MN: University of Minnesota Press.
- General Statistics Office of Vietnam (2015). Interactive statistics tables – area, population, and density. Retrieved from <http://gso.gov.vn/default.aspx?tabid=714>.
- Gilbert, M., Chaitaweesub, P., Parakamawongsa, T., Premasithira, S., Tiensin, T., Kalpravidh, W., & Slingenbergh, J. (2006). Free-grazing ducks and highly pathogenic avian influenza, thailand. *Emerging Infectious Diseases*, 12(2), 227–234. <https://doi.org/10.3201/eid1202.050640>.
- Gilbert, M., Xiao, X., Pfeiffer, D. U., Epprecht, M., Boles, S., Czarniecki, C., & Slingenbergh, J. (2008). Mapping H5N1 highly pathogenic avian influenza risk in southeast asia. *Proceedings of the National Academy of Sciences of the USA*, 105(12), 4769–4774. <https://doi.org/10.1073/pnas.0710581105>.
- Grossman, G. M., & Kreuger, A. B. (1995). Economic growth and the environment. *Quarterly Journal of Economics*, 110(2), 353–377. <https://doi.org/10.2307/2118443>.
- Guan, Y., Zheng, B. J., He, Y. Q., Liu, X. L., Zhuang, Z. X., Cheung, C. L., & Poon, L. L. M. (2003). Isolation and characterization of viruses related to the SARS coronavirus from animals in southern china. *Science*, 302(5643), 276–278. <https://doi.org/10.1126/science.1087139>.
- Handy, S. L., Boarnet, M. G., Ewing, R., & Killingsworth, R. E. (2002). How the built environment affects physical activity: Views from urban planning. *How the Built Environment Affects Physical Activity: Views from Urban Planning*, 23(2), 64–73. [https://doi.org/10.1016/S0749-3797\(02\)00475-0](https://doi.org/10.1016/S0749-3797(02)00475-0).
- Holdren, J. P., & Smith, K. R. (2000). Energy, the environment, and health. In J. Goldemberg, J. W. Baker, S. Ba-N'Daw, H. Khatib, A. Popescu & F. L. Viray (Eds.), *World energy assessment: Energy and the challenge of sustainability* (pp. 61–110). New York: U.N. Development Programme, U.N. Department of Economic and Social Affairs, World Energy Council. Retrieved from <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | <https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf> | [https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge](https://www.undp.org/content/dam/aplws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/world-energy-assessment-energy-and-the-challenge-of-sustainability/World%20Energy%20Assessment-2000.pdf)

- Spatial distribution and risk factors of highly pathogenic avian influenza (HPAI) H5N1 in china. *PLoS Pathogens*, 7(3), <https://doi.org/10.1371/journal.ppat.1001308>.
- Matthew, R. A., & McDonald, B. (2007). Cities under siege: Urban planning and the threat of infectious disease. *Journal of the American Planning Association*, 72(1), 109–117. <https://doi.org/10.1080/01944360608976728>.
- McGranahan, G., Songsore, J., Kjellen, M., Jacobi, P. R., & Surjadi, C. (2001). *The citizens at risk: From urban sanitation to sustainable cities*. London: Earthscan.
- McMichael, A. J., McKee, M., Shkolnikov, V., & Valkonen, T. (2004). Mortality trends and setbacks: Global convergence or divergence? *The Lancet*, 363(9415), 1155–1159. [https://doi.org/10.1016/S0140-6736\(04\)15902-3](https://doi.org/10.1016/S0140-6736(04)15902-3).
- Montgomery, M. R., Stren, R., Cohen, B., & Reed, H. E. (Eds.). (2003). *Cities transformed: Demographic change and its implications in the developing world*. Washington, D.C.: The National Academies Press. doi:10.17226/10693.
- Oliveira, C. C. G., Lacerda, H. G., Martins, D. R. M., Barbosa, J. D. A., Monteiro, G. R., Quieroz, J. W., & Jeronimo, S. M. B. (2004). Changing epidemiology of american cutaneous leishmaniasis (ACL) in brazil: A disease of the urban–rural interface. *Science Direct*, 90(2), 155–162. <https://doi.org/10.1016/j.actatropica.2003.11.011>.
- Pannell, C. W., & Ma, J. C. L. (1997). Urban transition and interstate relations in a dynamic post-soviet borderland: The xinjiang uygur autonomous region of china. *Post-Soviet Geography and Economics*, 38(4), 206–229. <https://doi.org/10.1080/10889388.1997.10641045>.
- Park, H., Russell, C., & Lee, J. (2007). National culture and environmental sustainability: A cross-national analysis. *Journal of Economics and Finance*, 31(1), 104–121. <https://doi.org/10.1007/BF02751516>.
- Peiris, J. S. M., de Jong, M. D., & Guan, Y. (2007). Avian influenza virus (H5N1): A threat to human health. *Clinical Microbiology Reviews*, 20(2), 243–267. <https://doi.org/10.1128/CMR.00037-06>.
- Pfeiffer, D. U., Minh, P. Q., Martin, V., Epprecht, M., & Otte, M. J. (2007). An analysis of the spatial and temporal patterns of highly pathogenic avian influenza occurrence in vietnam using national surveillance data. *The Veterinary Journal*, 174(2), 302–309. <https://doi.org/10.1016/j.tvjl.2007.05.010>.
- Portes, A. (2014). The downsides of social capital. *Proceedings of the National Academy of Sciences*, 111(52), 18407–18408. <https://doi.org/10.1073/pnas.1421888112>.
- Potts, D. (2017). Urban data and definitions in sub-saharan africa: Mismatches between the pace of urbanization and employment and livelihood change. *Urban Studies*, 55(5), 965–986. <https://doi.org/10.1177/0042098017712689>.
- Saelens, B. E., Sallis, J. F., & Frank, L. D. (2003). Environmental correlates of walking and cycling: Findings from the transportation, urban design and planning literatures. *Annals of Behavioral Medicine*, 25(2), 80–91. https://doi.org/10.1207/S15324796ABM2502_03.
- Saksena, S., Fox, J., Epprecht, M., Tran, C. C., Nong, D. H., Spencer, J. H., & Wilcox, B. A. (2015). Evidence for the convergence model: The emergence of highly pathogenic avian influenza (H5N1) in viet nam. *Plos One*, 10(9), <https://doi.org/10.1371/journal.pone.0138138>.
- Saksena, S., Fox, J., Spencer, J. H., Castrence, M., DiGregorio, M., Epprecht, M., & Vien, T. D. (2014). Classifying and mapping the urban transition in vietnam. *Applied Geography*, 50, 80–89. <https://doi.org/10.1016/j.apgeog.2014.02.010>.
- Shafik, N. (1994). Economic development and environmental quality: An econometric analysis. *Oxford Economic Papers*, 46(4), 757–773.
- Smith, K. R. (1990). The risk transition. *International Environmental Affairs*, 2, 227–251.
- Smith, K. R. (1997). Development, health, and the environmental risk transition. In G. S. Shahi, B. S. Levy, T. Kjellstrom, A. Binger, & R. Lawrence (Eds.). *International perspective in environment development, and health toward a sustainable world* (pp. 51–62). New York: Springer.
- Smith, K. R., & Akbar, S. (2003). Health-damaging air pollution: A matter of scale. In G. McGranahan, & F. Murray (Eds.). *Air pollution and health in rapidly developing countries* (pp. 1–20). London: Routledge. <https://doi.org/10.4324/9781849770460>.
- Spencer, J. H. (2007). Innovative systems to create peri-urban infrastructure: Assessment of a local partnership to provide water to the poor in vietnam. *International Development Planning Review*, 29(1), 1–22. <https://doi.org/10.3828/idpr.29.1.1>.
- Spencer, J. H. (2013). The urban health transition hypothesis: Empirical evidence of an avian influenza kuznets curve in vietnam? *Journal of Urban Health*, 90(2), 343–357. <https://doi.org/10.1007/s11524-012-9719-1>.
- Steck, J. (2006). Qu'est-ce que la transition urbaine ? croissance urbaine, croissance des villes, croissance des besoins à travers l'exemple africain. [What's Urban Transition? Urban Growth, Growth of Cities, Growth of Needs The African Example - with English summary] *Revue d'Économie Financière*, 86, 267–283. <https://doi.org/10.3406/ecofi.2006.4212>.
- Talhelm, T., Zhang, X., Oishi, S., Shimin, C., Duan, D., Lan, X., & Kitayama, S. (2014). Large-scale psychological differences within china explained by rice versus wheat agriculture. *Science*, 344(6184), 603–608. <https://doi.org/10.1126/science.1246850>.
- Tang, W., & Chung, H. (2002). Rural–urban transition in china: Illegal land use and construction. *Asia Pacific Viewpoint*, 43(1), 43–62. <https://doi.org/10.1111/1467-8373.00157>.
- To, K. G., Lee, J., Nam, Y., Trinh, O. T. H., & Do, D. V. (2016). Hand washing behavior and associated factors in vietnam based on the multiple indicator cluster survey. *Global Health Action*, 9(29207), <https://doi.org/10.3402/gha.v9.29207>.
- Turok, I., & McGranahan, G. (2013). Urbanization and economic growth: The arguments and evidence for africa and asia. *Environment and Urbanization*, 25(2), 465–482. <https://doi.org/10.1177/0956247813490908>.
- United Nations (2005). *Water: A shared responsibility*. Oxford: UNESCO and Berghahn Books.
- Waibel, M. (2006). The production of urban space in Vietnam's metropolis in the course of transition: Internationalization, polarization, and newly-emerging lifestyles in vietnamese society. *Dialog*, 89(2), 43–48.
- Weimann, A., Dai, D., & Oni, T. (2016). A cross-sectional and spatial analysis of the prevalence of multimorbidity and its association with socioeconomic disadvantage in south africa: A comparison between 2008 and 2012. *Social Science and Medicine*, 163, 144–156. <https://doi.org/10.1016/j.socscimed.2016.06.055>.
- Wilcox, B. A., & Colwell, R. R. (2005). Emerging and reemerging infectious diseases: Biocomplexity as an interdisciplinary paradigm. *Ecohealth*, 2(4), 244–257. <https://doi.org/10.1007/s10393-005-8961-3>.