Investigation into the rationale of migration intention due to air pollution integrating the *Homo Oeconomicus* traits

Quan-Hoang Vuong [1], Tam-Tri Le [1], Quang-Loc Nguyen [2], and Minh-Hoang Nguyen [1,*]

[1] Centre for Interdisciplinary Social Research, Phenikaa University, Ha Dong District, Hanoi 100803, Vietnam

[2] SP Jain School of Global Management, New South Wales 2141, Australia

* Correspondence: hoang.nguyenminh@phenikaa-uni.edu.vn

(Un-peer-reviewed manuscript v4)

November 12, 2021

* * * * *

Abstract

Air pollution is a considerable environmental stressor for urban residents in developing countries. Perceived health risks of air pollution might induce migration intention among inhabitants. The current study employed the Bayesian Mindsponge Framework (BMF) to investigate the rationale behind the domestic and international migration intentions among 475 inhabitants in Hanoi, Vietnam – one of the most polluted capital cities worldwide. We found that people perceiving more impacts of air pollution in their daily life are more likely to have migration intention. The effect of perceived air pollution impact on international migration intention is stronger than that of domestic migration. Acknowledging a family member's air pollution-induced sickness moderated the association between perceived air pollution impact and domestic migration intention, while the personal experience of air pollution-induced sickness did not. In contrast, the moderation effect of personal experience of sickness became significant in the international migration circumstance, but the effect of information about a family member's sickness was trivial. The findings suggest that urban inhabitants' consideration of air pollution averting strategies reflects some characteristics of *Homo Oeconomicus*. Additionally, the individual's socio-economic decision is seemingly insignificant on a social scale. Still, through environmental stressors as catalysts, such decisions might result in considerable social outcomes (e.g., internal migration and emigration).

Keywords: air pollution; migration intention; environmental stress; *Homo Oeconomicus*; Vietnam

1. Introduction

Nobody wants to live in a harmful environment if they can choose an alternative option. This is a natural tendency that can be observed in any evolutionary level of biological organisms. Negative chemotaxis (the migration of microorganisms in a direction corresponding to a chemical gradient) is observed in certain bacterium species as they move away from harmful substances (Adler, 1975; Pandey & Jain, 2002). More complex organisms have more complex interactions with their surroundings; for example, bees are particularly sensitive to environmental stressors, damaging their nervous system and leading to cognitive dysfunctions (Klein, Cabirol, Devaud, Barron, & Lihoreau, 2017). Many species migrate to places with better conditions in the animal kingdom, especially when their current habitat is unsuitable for survival or reproduction (e.g., due to seasonal change). But displacement is unfortunately not always due to natural reasons.

Pollution from human activities is one of the main reasons for habitat loss (National Wildlife Federation, 2021), making many areas no longer suitable for sustaining certain species. Humans are also biological organisms that naturally aim for optimal living conditions while avoiding harmful factors if possible. But arguably, unlike other species, humans use a much more complex rationale when deciding their responses to perceived risks (March, 1996). When people consider whether to migrate due to pollution, what would be the reasons behind their decision?

As a defensive response to the environmental stress caused by pollution, people can develop averting behaviors in humans. Such coping responses in a polluted urban environment vary as people may try to adapt by limiting outdoor exposure (Bresnahan, Dickie, & Gerking, 1997; Zivin & Neidell, 2009) and make changes to their everyday activities, such as skipping school (Currie, Hanushek, Kahn, Neidell, & Rivkin, 2009), reducing outdoor cycling (Saberian, Heyes, & Rivers, 2017) and public park visits (Noonan, 2014). People may decide to migrate on a larger scale due to environmental stress (Wolpert, 1966). Areas with high levels of air pollution were found to have decreased immigration rates (Kim, 2019) and immigrants' willingness to stay (Liu & Yu, 2020). Within a country, people tend to migrate away from regions having relatively worse air quality (Chen, Oliva, & Zhang, 2017; Germani, Scaramozzino, Castaldo, & Talamo, 2021; Gholipour, Farzanegan, & Javadian, 2020). People who are dissatisfied with their city's air quality are more likely to have internal migration intentions (Q.-H. Vuong, T.-T. Le, Q.-L. Nguyen, T. Q. Nguyen, & M.-H. Nguyen, 2021b).

Environmental stress can also induce international migration, and the cost-benefit approach for migrating decisions is important if we consider migrants' ability to choose among available alternatives (Hugo, 1996). A higher level of migration-related information-seeking activities was found to follow a higher measured level of air pollution from the day before (Qin & Zhu, 2018), which shows how the emigration interest is influenced by information inputs regarding the pollution status of one's living environment.

Intuitively, people are against living in a place with low air quality. Risk perception acts as a mediator for migration decisions driven by environmental hazards (Hunter, 2005). Air pollution does not only lead to subjective concerns and annoyance (Claeson, Lidén, Nordin, & Nordin, 2013), there are various serious health risks, both physically (Kampa & Castanas, 2008) and mentally (Sass et al., 2017; Vert et al., 2017). Bad air quality also decreases human productivity, including academic performance (Mohai, Kweon, Lee, & Ard, 2011) and physical and service work (Chang, Zivin, Gross, & Neidell, 2016; Li, Liu, & Salvo, 2015). Even worse, in the current pandemic, air pollution was also found to be a factor that increases the likelihood of COVID-19 death (Pozzer et al., 2020). With that being said, Hanoi city – where we collected survey data – is considered one of the most polluted capital cities in the world (Iqair, 2019) with air pollutants mainly from traffic, industrial emissions, and construction sites (Hien, Men, Tan, & Hangartner, 2020) that pose a considerable risk of respiratory and cardiovascular problems for the citizens (Phung et al., 2016).

Although environmental stress influences the intention to migrate, it is not the only factor in the complex consideration for such action. How do people assess their decisions on whether to migrate or not? Regarding the theoretical rationale leading to migration intention, humans have many different motives besides health concerns. The original approach of *Homo Oeconomicus* ("Economic Man") proposed by John Stuart Mill suggests that humans rationally aim for optimal personal economic benefits based on the psychology of desire (Persky, 1995). This view of a strictly rational decision-making model assumes that an individual has specific (and selfish) predetermined goals and will try to attain them at the lowest cost possible. The *Homo Oeconomicus* approach has received a lot of criticism (Fleming, 2017; Levitt & List, 2008), and studies have provided evidence for adjustment and expansion to the original theory (Henrich et al., 2001). While the view has its various flaws, it can help hint at a more integral cost-benefit model of subjective reasoning for human behavior.

Moving is costly in one way or another. For example, migration in insects can be considered in terms of cost and benefit across many aspects such as energy consumption, predation, or reproduction (Rankin & Burchsted, 1992). When choosing among places with suitable opportunities for the same purpose, people perceive migrating over a longer distance to be more costly, physically and financially (Miller, 1972), as well as in terms of information diminishing (Schwartz, 1973). Indeed, those who have migration intention in search of another city with better air quality are more likely to choose a nearby city rather than a faraway one as their destination (Vuong et al., 2021b). When migrating to a new environment, the cost of distance is physical and should be considered on the aspect of "cultural distance", or in other words, the complex effect of culture shock (Ward, Bochner, & Furnham, 2020).

Given the complexity of migration intention, to further explore its underlying rationality in response to perceived risks from environmental pollution, we examine the likelihood of having domestic and international migration intention driven by information of health consequences induced by air pollution from different sources (personal and family members). This study aims to deepen the understanding of the ideation of migrating behavior in terms of human information processing within socio-economic contexts.

2. Materials and method

2.1. Model construction

The Bayesian Mindsponge Framework (BMF), an analytical approach consolidating the Mindsponge mechanism and Bayesian inference (Nguyen & Le, 2021; Nguyen, Le, Ho, Nguyen, & Vuong, 2021), was employed as the methodological design for the current study. Thus, model construction in this subsection would be grounded on the information-processing mechanism of Mindsponge (Vuong, 2016; Vuong & Napier, 2015). The mindsponge mechanism is an inclusive model of cognition shifting processes that demonstrates how new values are absorbed from the external environment and waning values are ejected from the individual's mind. The process is "driven by a multi-filtering information process detecting and connecting insights (or information) among different disciplines as well as using inductive attitudes for plausible reasoning". In other words, the filters are based on reference information from the external environment and the individual's mindset simultaneously. The mindset (or a set of core values), which is the innermost part of the Mindsponge, defines the individual's identity, perceptions, attitudes, and behaviors.

The multi-filtering process includes two fundamental functions: 1) cost-benefit judgments; and, 2) trust evaluation. While the cost-benefit judgments are to determine the values of the information, the trust evaluation is to assess the certainty of that value. On the one hand, if the information is perceived to be beneficial, it will be absorbed closer towards the mindset. The closer the information is to the mindset, the stronger the filtering process will become. When the information is integrated into the mindset, it will influence the individual's subsequent thoughts and behaviors. On the other hand, the information will be dismissed from the mind when perceived as costly (in other words, if its net perceived benefit is negative). Therefore, ideation can only occur within the mind when the idea is deemed beneficial.

Following this logic, we assume that the migration ideation due to air pollution is more likely to emerge in the mind when an individual feels the negative impacts of air pollution on their life. In other words, when an individual becomes more aware of air pollution's adverse impacts on their life, they tend to find alternatives to minimize the cost of air pollution; such alternatives include migrating to other geographical locations. Thus, we postulate that the more an individual perceives the impacts of air pollution on their life, the more likely they will think of migrating to another city or country.

Perceived air pollution impacts can be myriad. Urban residents might attribute dust and smog, their uncomfortable feelings, shortness of breath, and respiratory diseases to the consequences of air pollution. Among these consequences, respiratory diseases are a severe impact of air pollution on an individual's health. Thus, we postulate that the association between perceived impacts of air pollution and migration intention can also be positively moderated by the individual's attribution of their respiratory diseases to the consequence of air pollution and knowing that a family member has been sick because of air pollution. This postulation can be explained in two ways.

First, a prior experience or knowledge of respiratory disease attributed to air pollution can affect the individual's trust evaluation process. In particular, it can increase trust, or certainty, towards the information regarding the negative effects of air pollution (e.g., economic and health losses) and reduce the evaluation rigor towards information related to air pollution countermeasures, which increases the emergence probability of migration ideation. Second, when individuals suffer from respiratory disease, they might be absent from work, or their working productivity might decline. Therefore, experiencing a respiratory disease might lead to income loss because of decreasing productivity or "discontinued operations". Such income loss adds to the cost-benefit judgment of the individual and increases the cost of staying (or increases the benefit of moving).

For these reasons, we constructed the prediction model of urban residents' migration ideation as follows:

$$MoveCity \sim \alpha + ImpactDegree + PersonalHealth * ImpactDegree + FamilyMemberHealth * ImpactDegree \quad (1)$$

When deciding to move, the distance from the current location to the speculated destination can also influence the probability of migrating because of the transportation cost. Even though the adverse air pollution impacts might be migration incentives, these incentives might decrease if the moving cost is expensive, especially if the migration destination is abroad. Moving to a foreign country generates higher economic costs and psychological and physical costs than domestic migration. Acculturation is a process that an individual has to adjust and adapt to the new culture after migration. While undergoing such processes, acculturative stress inflicted by culture shocks might arise and negatively affect the individual's psychological and physical wellbeing. As these costs are higher when migrating abroad than when migrating domestically, we suspected that the effects of perceived air pollution impacts, prior experience, and acknowledgment of respiratory disease attributed to air pollution on the probability to move to a foreign country would be lesser than the probability to move to another province.

$$MoveCountry \sim \alpha + ImpactDegree + PersonalHealth * ImpactDegree + FamilyMemberHealth * ImpactDegree \quad (2)$$

2.2. Materials

In this study, we used the data retrieved and combined from two open datasets about Hanoi inhabitants' perceptions towards air pollution (Van Khuc, Phu, & Luu, 2020). The two datasets were procured in two different survey collections using stratified random sampling methods at the central and suburban areas of the city, respectively. The survey collections were organized in November and December of 2019. Hanoi was chosen as the study site for the following three reasons: 1) Hanoi was ranked 7th among the most polluted capital cities around the world (Iqair, 2019); 2) Hanoi is one of the fastest-growing cities in Vietnam; 3) Hanoi is the second largest and most populous city in Vietnam.

According to Khuc et al. (Van Khuc et al.), the survey collection comprises three steps. First, the collectors were recruited and well-paid to encourage them to perform well during the collection process. The researchers also held two four-hour seminars to help the collectors understand the project's goals and the questionnaire before the collection began. During the seminars, essential skills and techniques were instructed to collectors for getting targeted information from respondents. The final version of the questionnaire was ensured to be error-free, straightforward, and easy to understand by conducting two pilot tests. Lastly, the collectors conducted face-to-face interviews with the respondents and maintained mutual interaction and communication to solve issues or questions arising during the survey collection.

Within the dataset, we purposely chose variables that could help explain the immigration intentions of Hanoi inhabitants due to air pollution. In total, we employed five variables for two models: two outcome variables and three predictor variables. The description of each variable is presented in Table 1.

Table 1: Variable description

Variable	Meaning	Type of variable	Value
MoveCity	Whether the respondent had the intention to move their family and work to a less polluted province due to air pollution concerns	Binary	No = 0 Yes = 1
MoveCountry	Whether the respondent had the intention to move their family and work to a less polluted foreign country due to air pollution concerns	Binary	No = 0 Yes = 1
PersonalHealth	Whether the respondent was sick because of air pollution	Binary	No = 0 Yes = 1
FamilyMemberHealth	Whether any member of the respondent's family was sick because of air pollution	Binary	No = 0 Do not know = 0 Yes = 1
ImpactDegree	The respondent's perceived impacts of air pollution on their life	Ordinal	From 1 (very impacted) to 4 (not impacted)

The outcome variable in Model 1 is *MoveCity*, generated from the question "Are you planning to move your family and work in another province with less pollution?". In contrast, the outcome variable in Model 2 is *MoveCountry*, generated from the question "Are you planning to move your family to a less polluted foreign country?" Both questions have two corresponding answers of 'yes' and 'no'. We generated two interaction variables, *PersonalHealth*ImpactDegree* and *FamilyMemberHealth*ImpactDegree*, from the above variables. The variable *PersonalHealth*ImpactDegree* is the interaction between two variables *PersonalHealth* and *ImpactDegree*, and the variable *FamilyMemberHealth*ImpactDegree* is the interaction between *FamilyMemberHealth* and *ImpactDegree* variables.

2.3. Methods and validation

The Bayesian analysis was employed in the current study because of its fitness with the complex model constructed by the Mindsponge mechanism. As the human psychological process is highly complex, we determined to construct parsimonious models to improve predictability. The Bayesian inference approach is a good method for estimating parsimonious models because it probabilistically treats all the properties, including the unknown parameters. Moreover, Bayesian analysis aided by the Markov Chain Monte Carlo (MCMC) algorithm offers the capability to estimate models with high complexity, like those in the current study with non-linear relationships. Estimating the non-linear relationships makes the model more complex and requires a larger sample size for sound estimation (Kerkhoff & Nussbeck, 2019). A large number of iterative samples generated by the stochastic processes of Markov chains can help fit complex models effectively.

It is important to note that science is currently facing a reproducibility crisis that many studies across different fields, including psychology (Baker, 2015) and social sciences (Collaboration, 2015), could not be replicated. The wide sample-to-sample variability in the *p*-value is suggested to be the main reason for the crisis (Halsey, Curran-Everett, Vowler, & Drummond, 2015). Thus, avoiding the use of *p*-value is another reason we employed Bayesian analysis besides its high compatibility with the Mindsponge framework. In addition, compared to the frequentist approach, Bayesian analysis provides a more precise estimation of small samples and asymmetric distributions thanks to MCMC and its independence of symmetry assumption (Dunson, 2001; Hahn & Doh, 2006).

Lastly, prior distribution incorporation is an advantage of Bayesian analysis. Even though we set priors as 'uninformative' to avoid the subjective influences over the simulated outcomes, the prior function still can be capitalized to check the robustness of the simulated results by performing the "prior-tweaking" technique.

For validating the simulated posterior outcomes, we adopt a three-pronged validation strategy. Initially, we used PSIS-LOO diagnostic plots to check a goodness-of-fit on every simulated model (Vehtari, Gelman, & Gabry). The model can be deemed a good fit with the data if the *k* values shown on the plot are all below 0.5. Next, we continued with the convergence check using diagnostic statistics and plots. The diagnostic statistics include the effective sample size (n_eff) and the Gelman shrink factor (Rhat), while the diagnostic plots include the trace, Gelman, and autocorrelation plots. Finally, the prior-tweaking technique was performed. Details of diagnostic statistics and plots are presented with explanation and interpretation in the Results section.

The **bayesvl** R package was used to conduct Bayesian analysis in this study for three reasons: first, it is a cost-effective alternative; second, its feature of visualizing graphics is eye-catching; and third, it is the easy-to-use package (Vuong, La, Nguyen, Ho, Ho, et al., 2020; Vuong, La, Nguyen, Ho, Tran, et al., 2020). For easy and transparent replication or cross-checking, the dataset, data description, and code snippets of Bayesian analysis were all deposited on The Open Science Framework (https://osf.io/us5tr/).

3. Results

To test the assumptions we made above, we conducted a Bayesian analysis to examine the models. For estimating these two models, we employed the 5,000-iteration MCMC simulation with 2,000 warm-up iterations and four Markov chains. All the models' simulated results and their technical validity are presented accordingly. The analysis was performed on the samples, with the proportion of male respondents being larger than that of female respondents (54.53% versus 45.26%). The age group between 10 and 30 accounted for the highest proportion of the samples (61.47%). Among 475 respondents, approximately 5% reported their intention to immigrate to another city, and about 7.6% of respondents intended to immigrate to a less polluted foreign country due to air pollution.

3.1. Model 1: Intention of immigration to other provinces

Model 1 examines the predictions of the perceived impact of air pollution and its interactions with prior negative experiences with air pollution towards immigration intention to a less polluted province. Model 1's logical connection is shown in Figure 1.

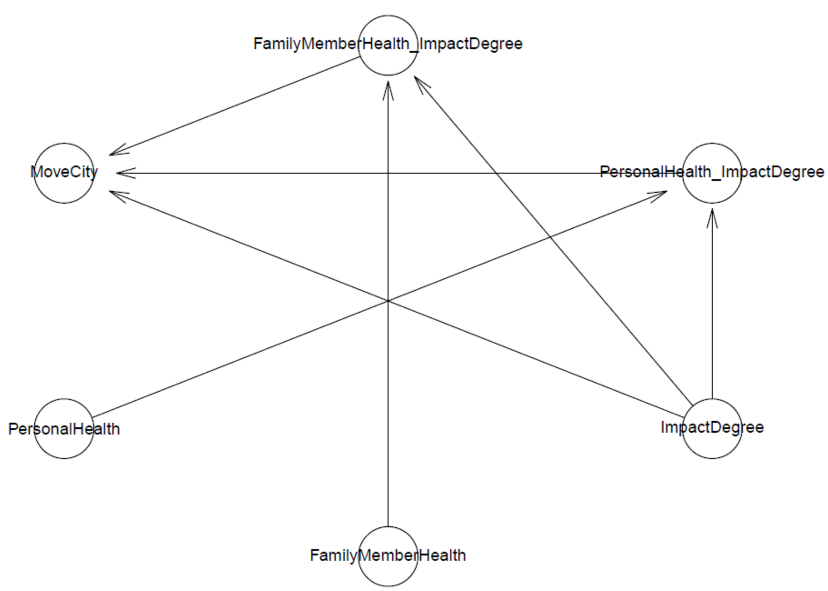

Figure 1: Model 1's logical network

The PSIS diagnostic plot shows that all *k* values are below 0.5, suggesting that Model 1 has a high goodness-of-fit with the data (see Figure 2).

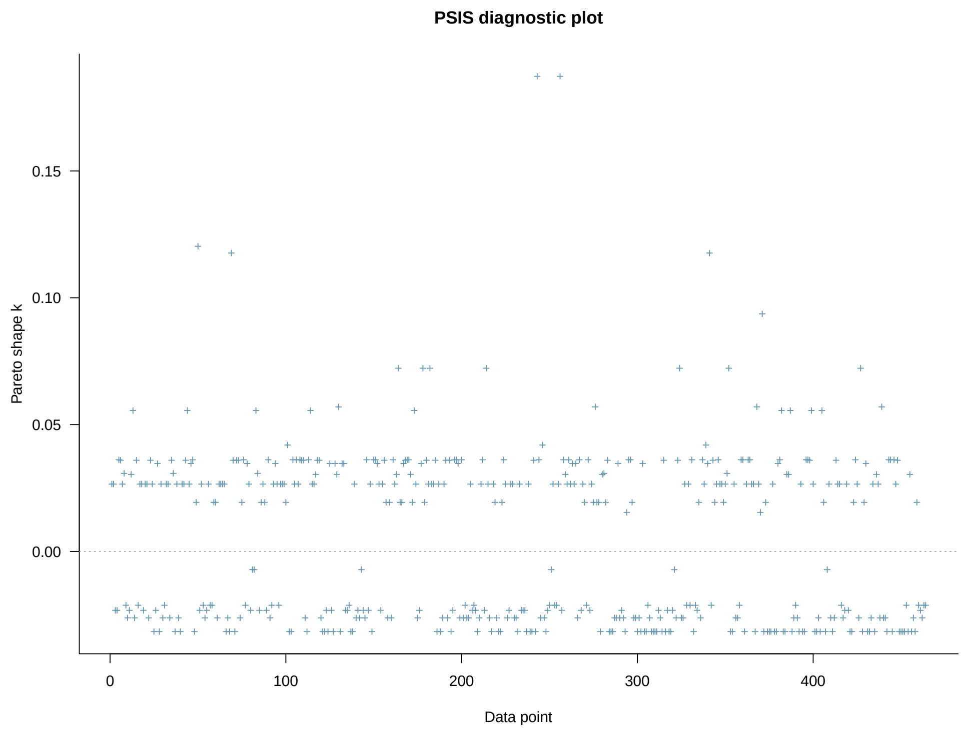

Figure 2: Model 1's PSIS diagnostic plot

The diagnostic statistics portray a good convergence of the model's Markov chains; the effective sample size (n_eff) statistics are larger than 1,000, and Gelman shrink factor (Rhat) statistics are equal to 1 (see Table 2). The convergence is also confirmed by the trace plots, autocorrelation plots, and Gelman plots.

Table 2: Model 1's simulated posteriors.

Parameters	**Uninformative**		**Belief**		**Disbelief**		**n_eff**	**Rhat**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**		
Constant	-1.90	0.49	-2.00	0.48	-1.89	0.48	4921	1
ImpactDegree	-0.48	0.29	-0.52	0.30	-0.46	0.29	4933	1
*PersonalHealth*ImpactDegree*	0.02	0.23	0.15	0.20	0.03	0.20	7545	1
*FamilyMemberHealth*ImpactDegree*	0.35	0.26	0.41	0.20	0.30	0.20	7541	1

Note:
* *SD = Standard deviation*
** *The effective sample size (n_eff) and Gelman value (Rhat) of simulated results with different priors are almost*

similar, so only the n_eff and Rhat of simulated results using uninformative priors are presented.

Trace plots of all posterior parameters are presented in Figure 3. The y-axis of the trace plot represents the posterior values of each parameter, while the x-axis represents the iteration order of the simulation. The Markov chains are the colored lines in the middle of the trace plot. If the Markov chains fluctuate around a central equilibrium, they can be considered good-mixing and stationary. These two characteristics are a good signal of convergence.

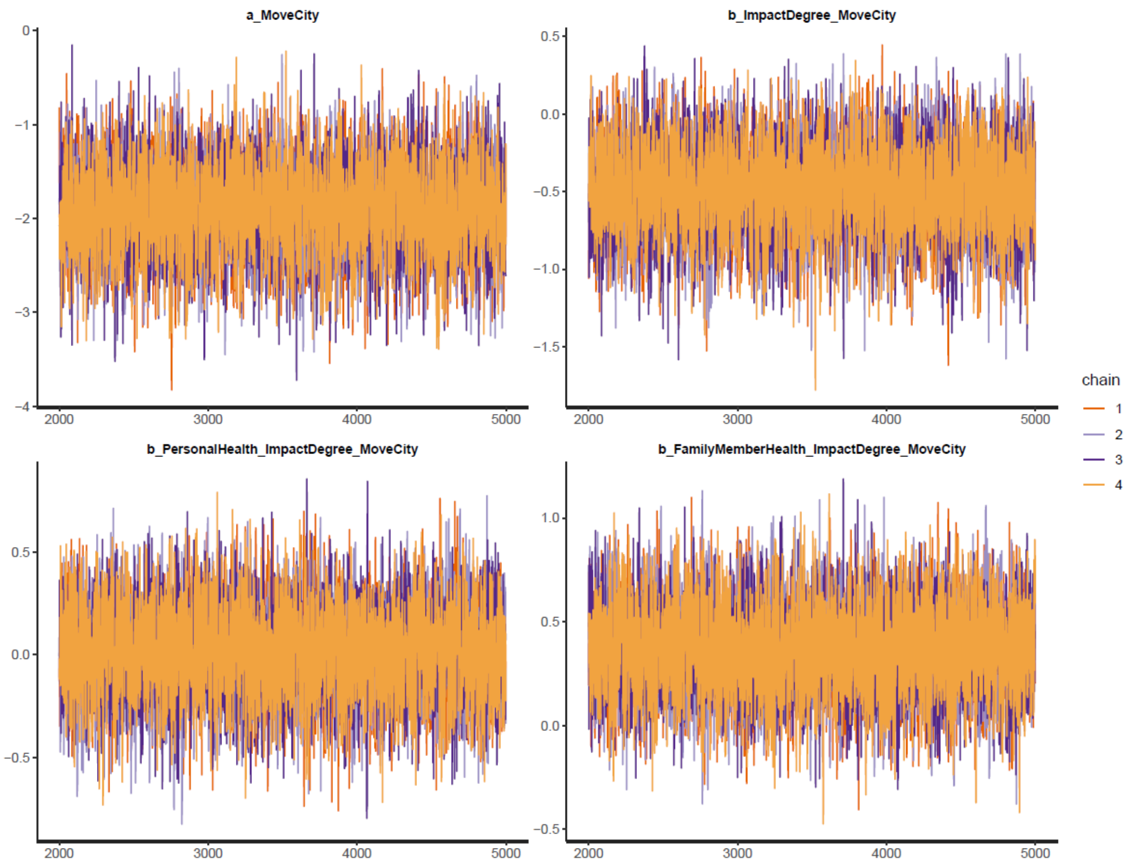

Figure 3: Trace plots for Model 1's posterior parameters

In Figure 4, Gelman plots of Model 1's parameters are illustrated. The y-axis of the Gelman plot illustrates the shrink factor (or Gelman factor), which is used to estimate the relative between the variance between Markov chains and the variance within chains. Meanwhile, the x-axis demonstrates the iteration order of the simulation. As can be seen that, the shrink factors of all parameters drop rapidly to 1 during the warm-up iterations (before the 2,000th iteration), hinting that there is no divergence among Markov chains. Therefore, the Markov property is held.

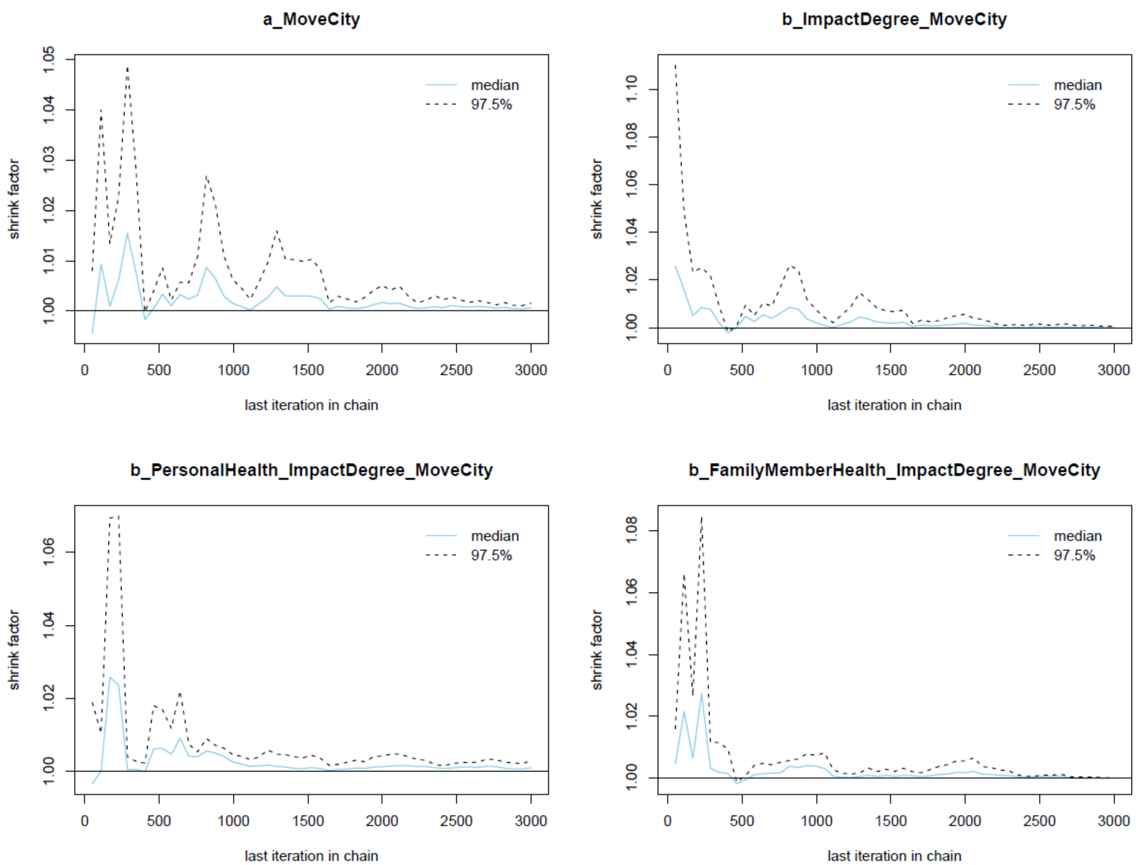

Figure 4: Gelman plots for Model 1's posterior parameters

The next step of validating Model 1's convergence is to diagnose the Markov chains' autocorrelation levels visually (see Figure 5). The Markov chains' lag is illustrated on the x-axes of the plots, and the average level of autocorrelation of each chain is presented on the y-axes. Figure 5 shows that the average autocorrelation level drops rapidly after the fourth lag, inducing all parameters to acquire a large number of effective samples. The autocorrelation plots' illustration again confirms the convergence of Model 1's Markov chains.

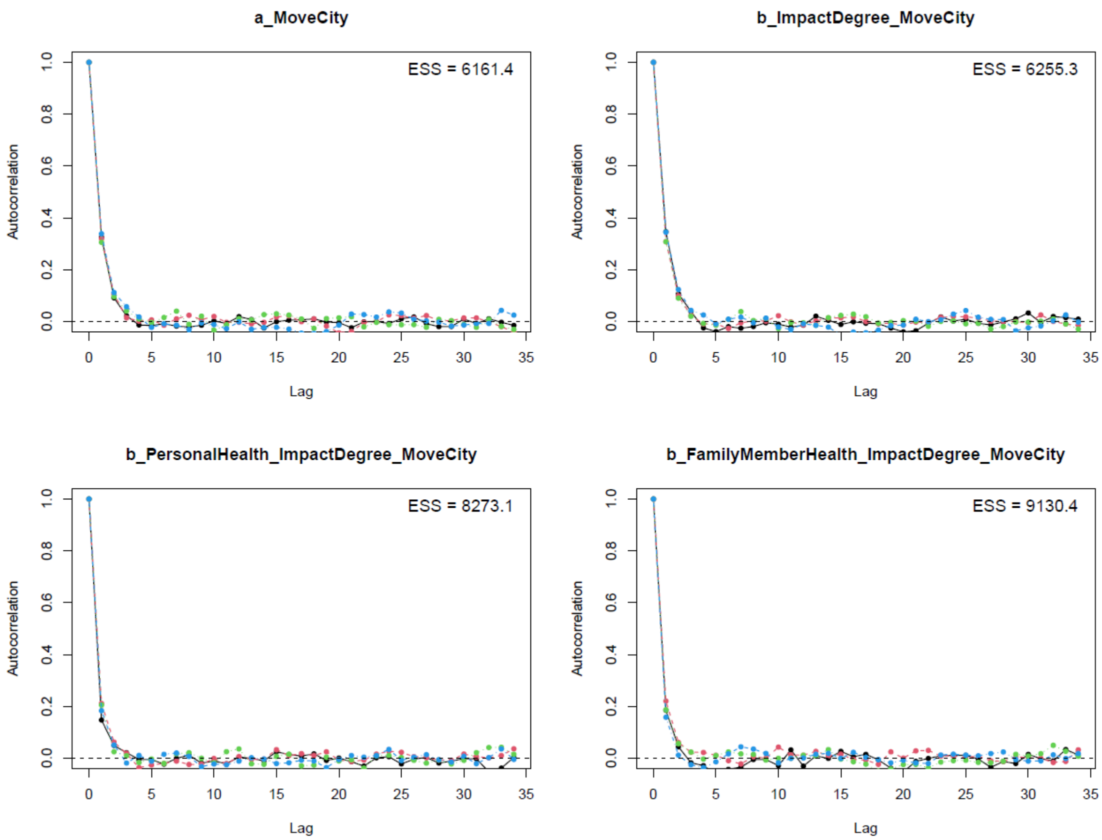

Figure 5: Autocorrelation plots for Model 1's posterior parameters

From the simulated posterior results of Model 1, we found that the perceived impact of air pollution was negatively associated with the intention to immigrate to another city ($\mu_{ImpactDegree} = -0.48$ and $\sigma_{ImpactDegree} = 0.29$). This result confirms our assumption that the more an individual perceives the impacts of air pollution on their life, the more likely they will think of migrating to another city or country. However, the cost-benefit judgment of urban citizens about migration due to air pollution is much more complex. Perceived negative health effect caused by air pollution on family member increases the probability of domestic migration intention ($\mu_{FamilyMemberHealth*ImpactDegree} = 0.35$ and $\sigma_{FamilyMemberHealth*ImpactDegree} = 0.26$), whereas the effect of prior negative personal experience attributed to air pollution is minimal and could be neglected ($\mu_{PersonalHealth*ImpactDegree} = 0.02$ and $\sigma_{PersonalHealth*ImpactDegree} = 0.23$).

For robustness check, prior-tweaking was performed. In both cases, demonstrating our beliefs and disbeliefs on the associations, the coefficients' effect patterns did not change, even though the degree slightly changed. Thus, it is conclusive that the effects in Model 1 are robust even when the prior beliefs vary.

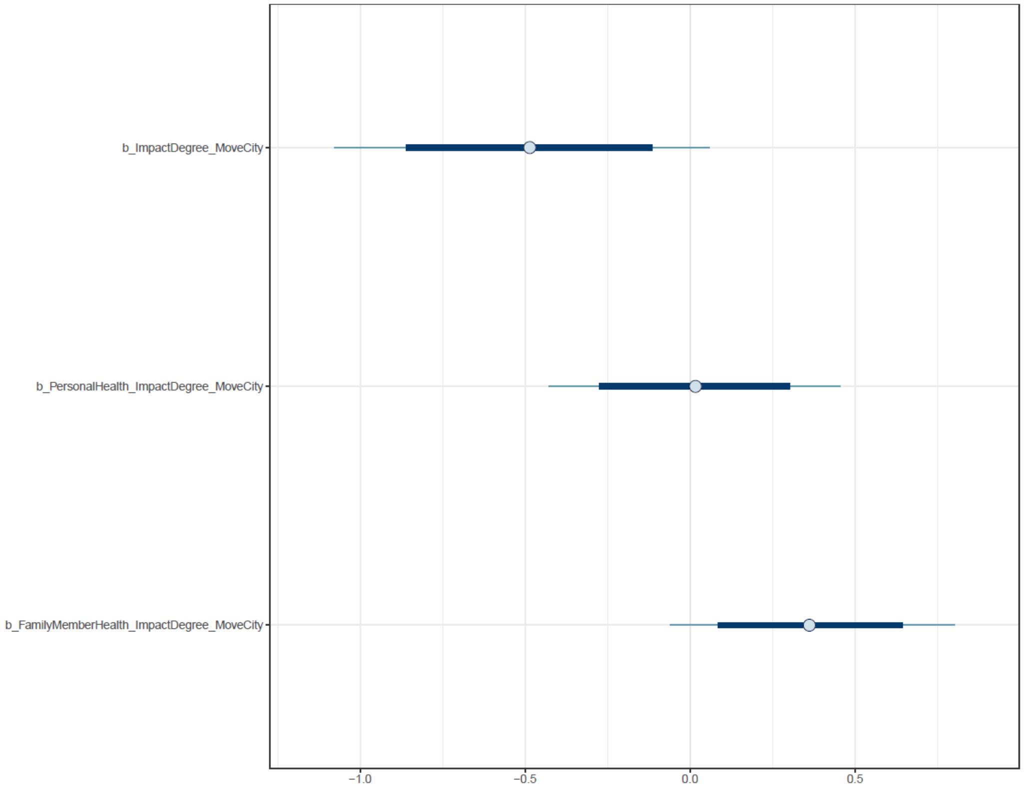

Figure 6: Distributions of Model 1's posterior coefficients estimated with uninformative priors.

The distributions of Model 1's parameters estimated with uninformative priors are visualized in the interval plot for assessing their reliability (see Figures 6). The probability distributions of parameters are shown in the x-axis of the plot. Most of the distribution of *ImpactDegree* lies on the negative side of the axis, indicating a highly reliable negative association between *ImpactDegree* and *MoveCity*. The distribution of *FamilyMemberHealth*ImpactDegree* is located on the positive side, implying that a family member's perceived negative health effect had the highest probability to positively moderate the effect of perceived air pollution impact on domestic migration intention. It is shown in Figure 5 that the distribution of *PersonalHealth*ImpactDegree* is near 0 and has a high standard deviation, so the moderation effect of *PersonalHealth* is not significant.

3.2. Model 2: Emigration intention to another country with lower air pollution level

In the second model, we examined the perceived air pollution impact on the citizens' lives and its interactions with prior personal experience of respiratory disease. We perceived her/his family member's health effect caused by contaminated air on foreign migration intention. The logical network of Model 2 can be illustrated in Figure 7.

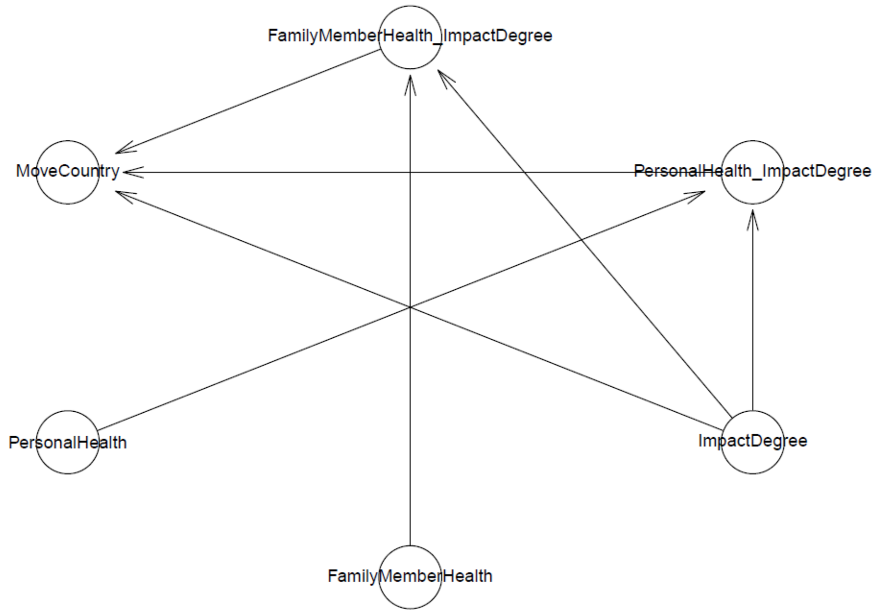

Figure 7: Model 2's logical network

The model's goodness-of-fit is relatively high as no k values on the PSIS diagnostic plot are higher than 0.5 (see Figure 8).

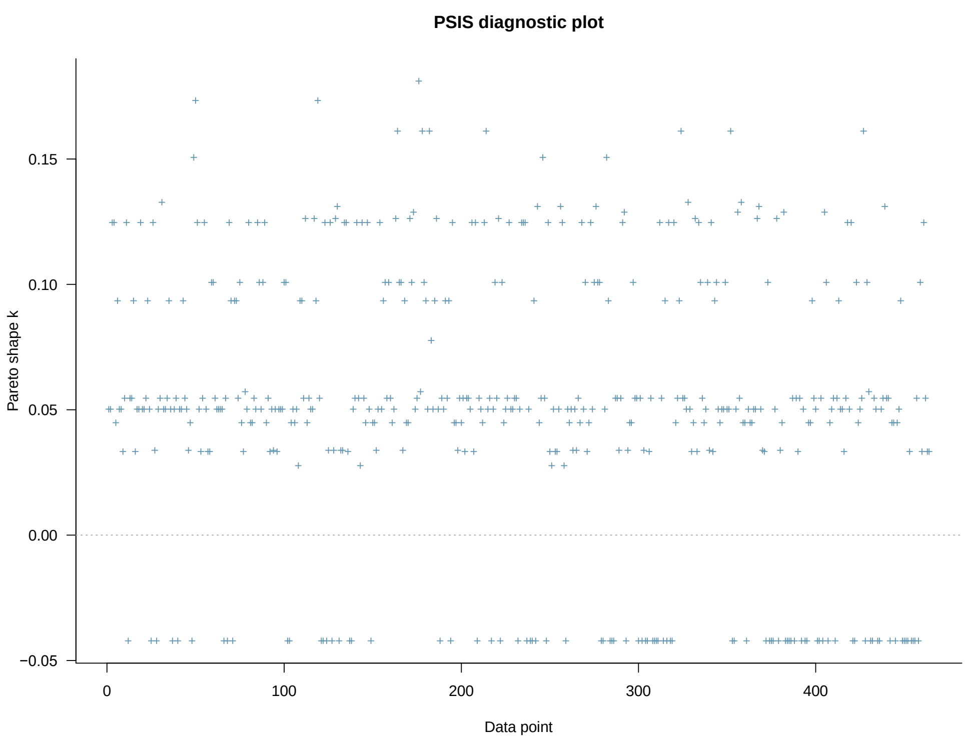

Figure 8: Model 2's PSIS diagnostic plot

The diagnostic statistics of Model 2 indicate that the posterior results are well convergent; the n_eff values are greater than 1,000, and Rhat values are equal to 1. The visual diagnostic methods, like the trace plots (see Figure A1), the Gelman plots (see Figure A2), and the autocorrelation plots (see Figure A3), also confirm Model 2's Markov chains' convergence.

Table 3: Model 2's simulated posterior coefficients

Parameters	**Uninformative**		**Belief**		**Disbelief**		**n_eff**	**Rhat**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**		
Constant	-1.74	0.55	-1.82	0.55	-1.69	0.54	5261	1
ImpactDegree	-0.78	0.36	-0.86	0.37	-0.76	0.34	5513	1
*PersonalHealth*ImpactDegree*	0.42	0.28	0.48	0.24	0.31	0.24	7542	1
*FamilyMemberHealth*ImpactDegree*	-0.09	0.27	0.11	0.24	-0.04	0.23	8015	1

Note:
** SD = Standard deviation*
*** The effective sample size (n_eff) and Gelman value (Rhat) of simulated results with different priors are almost similar, so only the n_eff and Rhat of simulated results using uninformative priors are presented.*

From the simulated posterior results of Model 2, we found that the perceived air pollution on life was negatively associated with the intention to migrate to a less polluted country ($\mu_{ImpactDegree} = -0.78$ and $\sigma_{ImpactDegree} = 0.36$). This result is similar to Model 1's outcome, confirming our assumption that the higher degree of perceived air pollution impacts, the higher the probability people intended to migrate abroad. However, the moderation effects of personal experience of health issues and her/his relative's health effect caused by air pollution are different from Model 1's outcomes. Prior negative personal experiences caused by air pollution increased the probability of foreign migration intention ($\mu_{PersonalHealth*ImpactDegree} = 0.42$ and $\sigma_{PersonalHealth*ImpactDegree} = 0.28$), whereas the moderation effect of *AirDisease* on the relationship between *ImpactDegree* and *MoveCountry* was negligible ($\mu_{FamilyMemberHealth*ImpactDegree} = -0.09$ and $\sigma_{FamilyMemberHealth*ImpactDegree} = 0.27$). Using the prior-tweaking techniques, we also found no significant changes in the simulated posterior results of Model 2. All coefficients' probability distributions are presented in Figure 9.

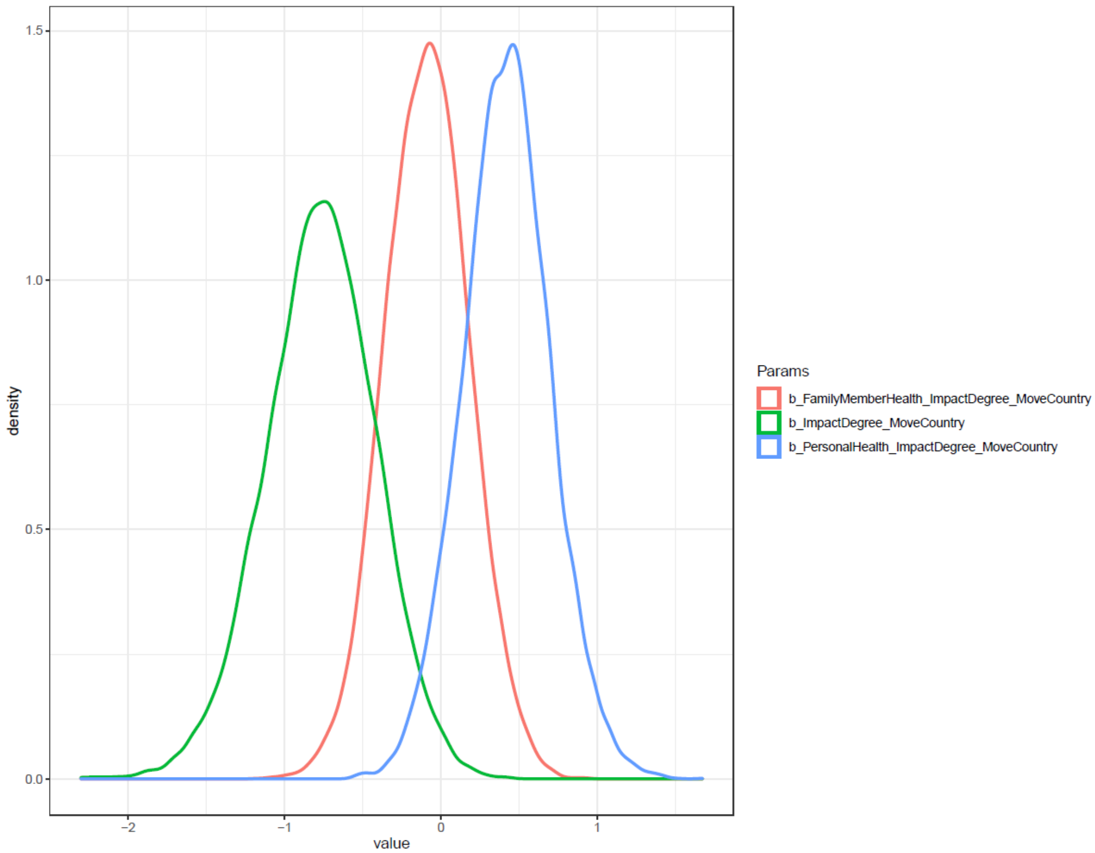

Figure 9: Distributions of Model 2's posterior coefficients on a density plot.

4. Discussion

In this study, we employed the BMF to construct and analyze models to predict the domestic and foreign migration intention among Vietnamese urban residents. Estimated results based on 475 inhabitants in Hanoi - one of the most polluted capital cities in the world - validate our assumptions that people perceiving more air pollution impacts would be more likely to migrate domestically and abroad. Although prior experience and acknowledgment of respiratory disease attributed to air pollution increase the migration probability, their effects on domestic and international migration intentions were inconsistent. Specifically, while prior experiences of respiratory disease caused by air pollution positively moderated the association between perceived air pollution impact and international migration intention, the acknowledgment of family members' sickness caused by air pollution did not. These moderation effects became opposite when the intention was domestic migration.

One possible explanation for these strange results is that respondents' consideration of long-term income in our postulations was previously not sufficiently assessed. In most cases, moving to another place and starting a new job can be considered a lifetime decision. It is not easy to make, regardless of whether the destination is domestic or international. In our earlier postulation in the Model Construction subsection, health was deemed a vital factor that could adversely affect inhabitants' wellbeing and short-term income (due to "discontinued operations"), which could eventually drive inhabitants to migrate. However, on the other side of the coin, the state of wellbeing could not be sustained in the long term if the economic conditions were not guaranteed. Thus, given that migration is a lifetime decision, migration ideation induced by air pollution would be more likely to happen when two main conditions are met: 1) the expected destination has a less polluted environment that could improve the individual's wellbeing, and 2) individual could acquire the economic opportunities in the expected destination to sustain their life and regain the cost spent on moving.

While the first condition can be easily met because many places within and beyond Vietnam are less polluted than Hanoi, the second condition seems more difficult to meet domestically since Hanoi's job opportunities are among the highest in Vietnam. In a prior study on Hanoi inhabitants' migration intention, we found that people's domestic migration probability is influenced by the perceived availability of less polluted provinces. Still, the effect shrinks if the distance cost is high (Q.-H. Vuong, T.-T. Le, Q.-L. Nguyen, Q.-T. Nguyen, & M.-H. Nguyen, 2021a). Interpretively, health costs inflicted by air pollution might be a vital element that drives moving ideation, but economic factors cannot be separated from the cost-benefit judgment process of migration.

International migration is different. Markets in many high-income countries are more developed than those in Vietnam, so international migration can be perceived as a way to improve quality of life and acquire better job opportunities. A country's emigrant population generally rises until that country reaches the upper-middle-income level (Clemens, 2014). This might also explain why perceived air pollution impacts had a stronger effect on the international migration intention than domestic migration intention, as shown in our results.

But, why could only the respondent's prior experience of respiratory disease improve the effect of perceived air pollution impacts on international migration intention, and their acknowledgment of family member's sickness did not? The result somewhat reflects the traits of *Homo Oeconomicus*, who always act to maximize utilities given the perceived constraints and opportunities among respondents. Assuming that domestic or international migration will result in better health outcomes, the migration decision will be greatly subject to economic factors. Three major economic factors are involved in the cost-benefit judgment of the migration process: 1) job opportunity, 2) moving cost, and 3) income loss due to "discontinued operation" caused by air pollution. When a family member is sick because of air pollution, the individual's job is not discontinued, so it is plausible to say that the respondent is not sensitive to the income loss caused by "discontinued operation".

In contrast, when the individual experiences respiratory disease attributed to air pollution, their income is lost due to "discontinued operations". Their perception of income loss due to "discontinued operations" caused by air pollution is more transparent. Therefore, income loss due to "discontinued operation" is more likely to be considered when the individual experiences air pollution-related disease than when knowing their family member is sick.

As presented above, the job opportunities in Hanoi are among the highest in Vietnam, so moving domestically might not generate an economic surplus. In this case, moving costs will be considered an exchange for better health. Suppose the individual personally experiences the sickness and perceives income loss due to “discontinued operations”. In that case, the domestic migration ideation will be less likely to emerge because they might perceive fewer opportunities to regain the income loss in the destination. When moving internationally, an expected economic surplus is much higher than that of domestic migration. The surplus often even bypasses the moving cost in circumstances of people migrating from low-income to high-income countries (Clemens, 2014). In addition, the expectation of no income loss due to “discontinued operations” due to air pollution and the opportunity to regain the previous loss in a foreign destination also adds more perceived benefit to the migration ideation during the cost-benefit judgment process. On the contrary, acknowledging family members’ sickness induced by air pollution does not influence the international migration intention because the individual feels no pressure about the income loss due to “discontinued operation”.

The above explanations only focus on the economic aspect of the cost-benefit judgment to highlight some traits of *Homo Oeconomicus* among the respondents, so we assume domestic and international migration generate the same level of health-related benefit. Nevertheless, foreign countries that are economically more developed also have better living standards, including environmental quality, such as some North American and European countries, Japan, South Korea, etc. Comparatively, Vietnam is only ranked 141st on Environmental Performance Index (Wendling, Emerson, de Sherbinin, Esty, & al., 2020). As a result, besides economic factors, the ideal living conditions in developed countries compared to domestic cities also substantially contribute to the migration decision due to air pollution.

Based on the presented results and discussion, we advocate that environmental issues should not be concerned within the boundary of the environmental study itself. Still, the consideration needs to encompass economics and sociology. The cost-benefit judgments of socio-economic values may appear seemingly trivial, but they can be facilitated by environmental stressors as catalysts, which might eventually lead to mass migration, especially when low- and middle-income countries are more severely affected by not only air pollution but also climate change problems (Feng, Krueger, & Oppenheimer, 2010). For preventing the environmental problems from exacerbating, besides political interventions and technological infrastructure development (Vuong, Ho, Nguyen, & Nguyen, 2019), it is necessary to replace the current ‘eco-deficit culture’ among the Global South countries with the ‘eco-surplus culture’, especially among private sectors (Q.-H. Vuong, 2021; Vuong, La, Ho, Trang, & Ho, 2020; Q. H. Vuong, 2021).

Our study’s limitations are presented here for transparency (Vuong, 2020). First of all, the explanation of the estimated results using the traits of *Homo Oeconomicus* is speculative, so further studies on migration due to environmental stressors are needed to examine the associations of *Homo Oeconomicus* characteristics with migration decisions. Secondly, the samples were collected only in an urban area, so the study findings might not be representative of the associations of health and economic factors with migration intention among rural residents. Moreover, as our interpretations were made based on Hanoi's environmental and economic development levels, the impacts of health and economic factors on the migration consideration should be validated using samples from other urban areas in developing countries, but not limited to Vietnam.

Appendix

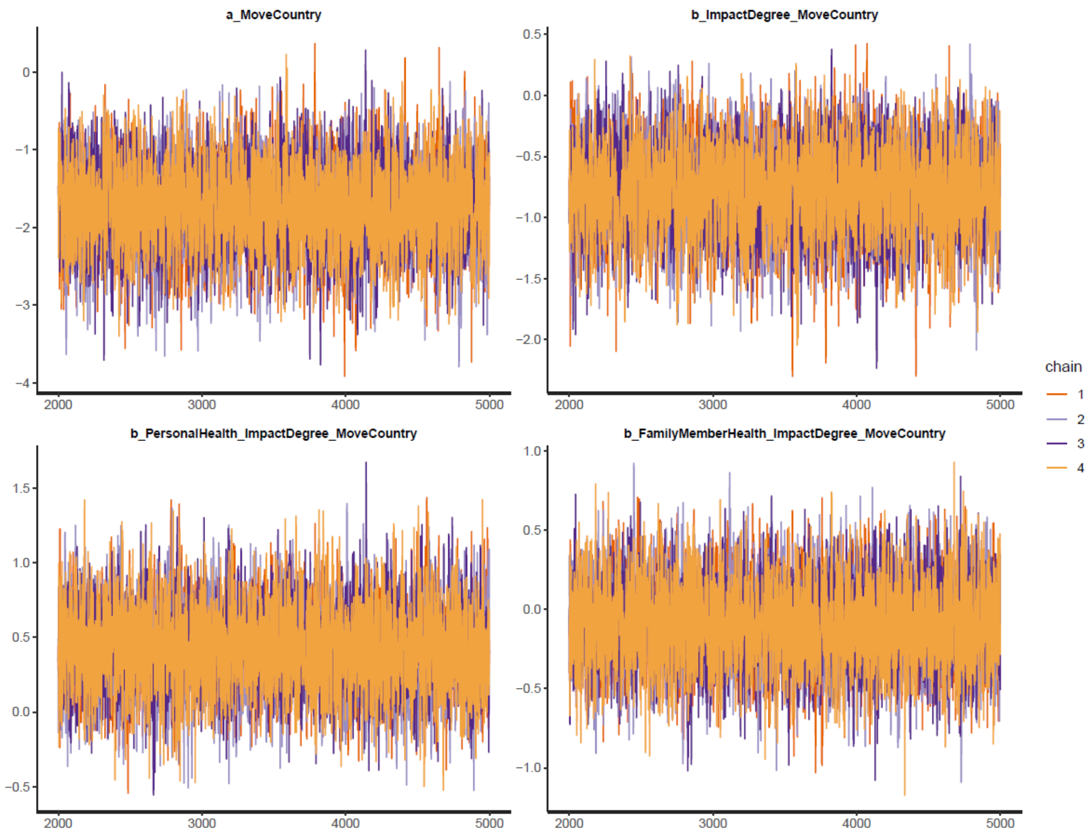

Figure A1: Trace plots for Model 2's posterior parameters

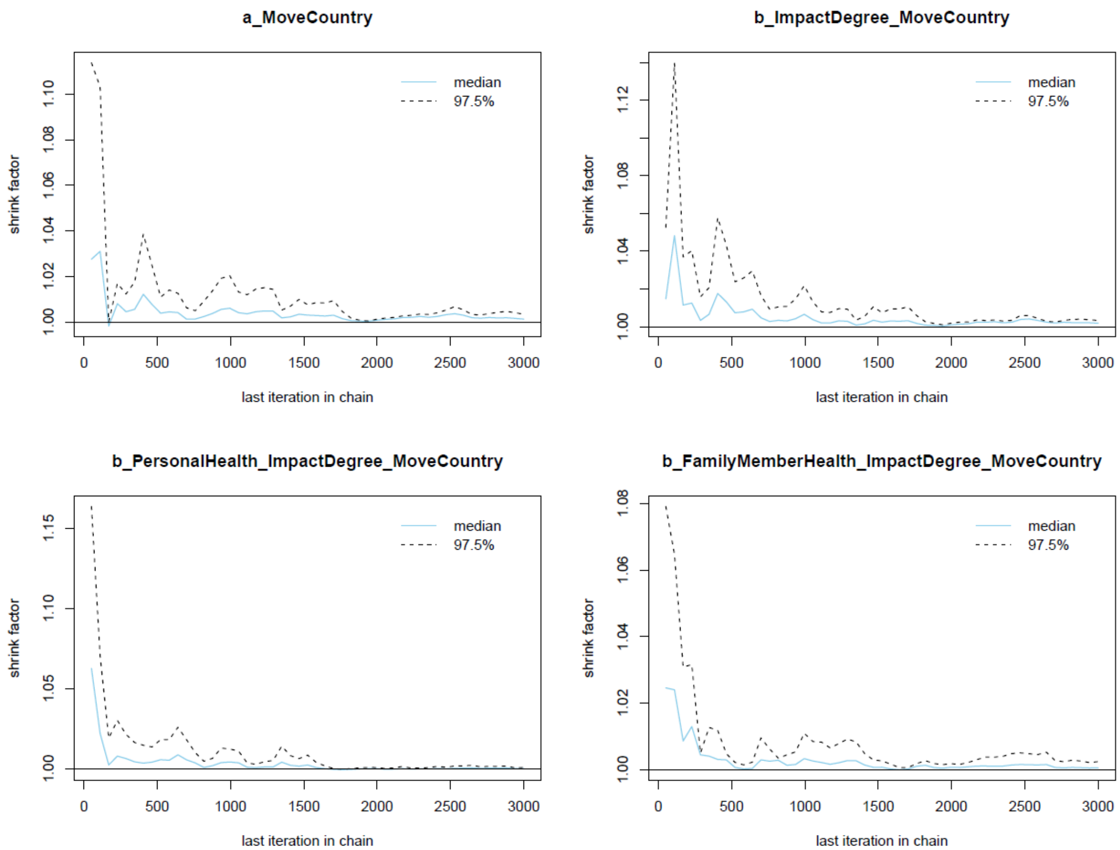

Figure A2: Gelman plots for Model 2's posterior parameters

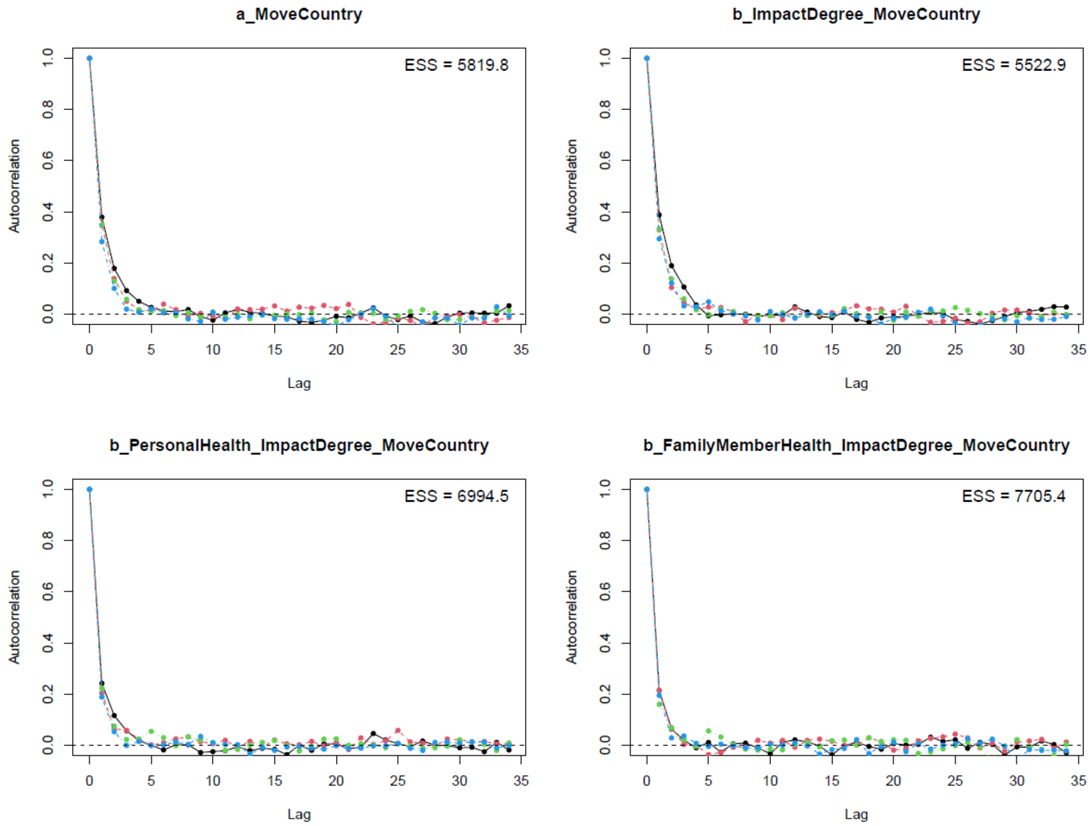

Figure A3: Autocorrelation plots for Model 2's posterior parameters

References

Adler, J. (1975). Chemotaxis in Bacteria. *Annual Review of Biochemistry*, *44*(1), 341-356. doi:10.1146/annurev.bi.44.070175.002013

Baker, M. (2015). Over half of psychology studies fail reproducibility test. *Nature News*, *27*.

Bresnahan, B. W., Dickie, M., & Gerking, S. (1997). Averting Behavior and Urban Air Pollution. *Land Economics*, *73*(3), 340. doi:10.2307/3147172

Chang, T., Zivin, J. G., Gross, T., & Neidell, M. (2016). *The Effect of Pollution on Worker Productivity: Evidence from Call-Center Workers in China* (w22328). Retrieved from Cambridge, MA: http://www.nber.org/papers/w22328.pdf

Chen, S., Oliva, P., & Zhang, P. (2017). *The Effect of Air Pollution on Migration: Evidence from China* (w24036). Retrieved from Cambridge, MA: http://www.nber.org/papers/w24036.pdf

Claeson, A.-S., Lidén, E., Nordin, M., & Nordin, S. (2013). The role of perceived pollution and health risk perception in annoyance and health symptoms: a population-based study of odorous air pollution. *International Archives of Occupational and Environmental Health*, *86*(3), 367-374. doi:10.1007/s00420-012-0770-8

Clemens, M. A. (2014). Does development reduce migration? In R. E. B. Lucas (Ed.), *International handbook on migration and economic development*. Cheltenham: Edward Elgar Publishing.

Collaboration, O. S. (2015). Estimating the reproducibility of psychological science. *Science, 349*(6251), aac4716. doi:10.1126/science.aac4716

Currie, J., Hanushek, E. A., Kahn, E. M., Neidell, M., & Rivkin, S. G. (2009). Does Pollution Increase School Absences? *The Review of Economics and Statistics, 91*(4), 682-694. doi:10.1162/rest.91.4.682

Dunson, D. B. (2001). Commentary: Practical Advantages of Bayesian Analysis of Epidemiologic Data. *American Journal of Epidemiology, 153*(12), 1222-1226. doi:10.1093/aje/153.12.1222

Feng, S., Krueger, A. B., & Oppenheimer, M. (2010). Linkages among climate change, crop yields and Mexico–US cross-border migration. *Proceedings of the National Academy of Sciences, 107*(32), 14257-14262.

Fleming, P. (2017). *The death of Homo Economicus: work, debt and the myth of endless accumulation*. London: Pluto Press.

Germani, A. R., Scaramozzino, P., Castaldo, A., & Talamo, G. (2021). Does air pollution influence internal migration? An empirical investigation on Italian provinces. *Environmental Science & Policy, 120*, 11-20. doi:10.1016/j.envsci.2021.02.005

Gholipour, H. F., Farzanegan, M. R., & Javadian, M. (2020). *Air Pollution and Internal Migration: Evidence from Iranian Household Survey* (ID 3541456). Retrieved from Rochester, NY: https://papers.ssrn.com/abstract=3541456

Hahn, E. D., & Doh, J. P. (2006). Using Bayesian methods in strategy research: an extension of Hansenet al. *Strategic management journal, 27*(8), 783-798.

Halsey, L. G., Curran-Everett, D., Vowler, S. L., & Drummond, G. B. (2015). The fickle P value generates irreproducible results. *Nature methods, 12*(3), 179-185.

Henrich, J., Boyd, R., Bowles, S., Camerer, C., Fehr, E., Gintis, H., & McElreath, R. (2001). In Search of Homo Economicus: Behavioral Experiments in 15 Small-Scale Societies. *American Economic Review, 91*(2), 73-78. doi:10.1257/aer.91.2.73

Hien, P., Men, N., Tan, P., & Hangartner, M. (2020). Impact of urban expansion on the air pollution landscape: A case study of Hanoi, Vietnam. *Science of the Total Environment, 702*, 134635. doi:10.1016/j.scitotenv.2019.134635

Hugo, G. (1996). Environmental Concerns and International Migration. *International Migration Review, 30*(1), 105-131. doi:10.1177/019791839603000110

Hunter, L. M. (2005). Migration and Environmental Hazards. *Population and Environment, 26*(4), 273-302. doi:10.1007/s11111-005-3343-x

Iqair. (2019). World Air Quality Report 2019 - Region and City PM2.5 Ranking. In: IQAir.

Kampa, M., & Castanas, E. (2008). Human health effects of air pollution. *Environmental Pollution, 151*(2), 362-367. doi:10.1016/j.envpol.2007.06.012

Kerkhoff, D., & Nussbeck, F. W. (2019). The Influence of Sample Size on Parameter Estimates in Three-Level Random-Effects Models. *Frontiers in Psychology, 0*. doi:10.3389/fpsyg.2019.01067

Kim, B. (2019). Do Air Quality Alerts Affect Household Migration? *Southern Economic Journal, 85*(3), 766-795. doi:10.1002/soej.12310

Klein, S., Cabirol, A., Devaud, J.-M., Barron, A. B., & Lihoreau, M. (2017). Why Bees Are So Vulnerable to Environmental Stressors. *Trends in Ecology & Evolution, 32*(4), 268-278. doi:10.1016/j.tree.2016.12.009

Levitt, S. D., & List, J. A. (2008). Homo economicus Evolves. *Science, 319*(5865), 909-910. doi:10.1126/science.1153640

Li, T., Liu, H., & Salvo, A. (2015). Severe Air Pollution and Labor Productivity. *SSRN Electronic Journal*. doi:10.2139/ssrn.2581311

Liu, Z., & Yu, L. (2020). Stay or Leave? The Role of Air Pollution in Urban Migration Choices. *Ecological Economics, 177*, 106780. doi:10.1016/j.ecolecon.2020.106780

March, J. G. (1996). Learning to be risk averse. *Psychological Review, 103*(2), 309-319. doi:10.1037/0033-295X.103.2.309

Miller, E. (1972). A note on the role of distance in migration: costs of mobility versus intervening opportunities. *Journal of Regional Science, 12*(3), 475-478. doi:10.1111/j.1467-9787.1972.tb00369.x

Mohai, P., Kweon, B.-S., Lee, S., & Ard, K. (2011). Air Pollution Around Schools Is Linked To Poorer Student Health And Academic Performance. *Health Affairs, 30*(5), 852-862. doi:10.1377/hlthaff.2011.0077

National Wildlife Federation. (2021). Habitat Loss. *National Wildlife Federation.* Retrieved from https://www.nwf.org/Home/Educational-Resources/Wildlife-Guide/Threats-to-Wildlife/Habitat-Loss

Nguyen, M.-H., & Le, T.-T. (2021). Bayesian Mindsponge Framework. In *Scholarly Community Encyclopedia*. Basel, Switzerland: MDPI AG.

Nguyen, M.-H., Le, T.-T., Ho, M.-T., Nguyen, H. T. T., & Vuong, Q.-H. (2021). Alice in Suicideland: Exploring the Suicidal Ideation Mechanism through the Sense of Connectedness and Help-Seeking Behaviors. *International Journal of Environmental Research and Public Health, 18*(7), 3681. doi:https://doi.org/10.3390/ijerph18073681

Noonan, D. S. (2014). Smoggy with a Chance of Altruism: The Effects of Ozone Alerts on Outdoor Recreation and Driving in Atlanta. *Policy Studies Journal, 42*(1), 122-145. doi:10.1111/psj.12045

Pandey, G., & Jain, R. K. (2002). Bacterial Chemotaxis toward Environmental Pollutants: Role in Bioremediation. *Applied and Environmental Microbiology*, *68*(12), 5789-5795. doi:10.1128/AEM.68.12.5789-5795.2002

Persky, J. (1995). The Ethology of Homo Economicus. *Journal of Economic Perspectives, 9*(2), 221-231. doi:10.1257/jep.9.2.221

Phung, D., Hien, T. T., Linh, H. N., Luong, L. M., Morawska, L., Chu, C., . . . Thai, P. K. (2016). Air pollution and risk of respiratory and cardiovascular hospitalizations in the most populous city in Vietnam. *Science of the Total Environment, 557*, 322-330. doi:10.1016/j.scitotenv.2016.03.070

Pozzer, A., Dominici, F., Haines, A., Witt, C., Münzel, T., & Lelieveld, J. (2020). Regional and global contributions of air pollution to risk of death from COVID-19. *Cardiovascular Research, 116*(14), 2247-2253. doi:10.1093/cvr/cvaa288

Qin, Y., & Zhu, H. (2018). Run away? Air pollution and emigration interests in China. *Journal of Population Economics, 31*(1), 235-266. doi:10.1007/s00148-017-0653-0

Rankin, M. A., & Burchsted, J. C. A. (1992). The Cost of Migration in Insects. *Annual Review of Entomology, 37*(1), 533-559. doi:10.1146/annurev.en.37.010192.002533

Saberian, S., Heyes, A., & Rivers, N. (2017). Alerts work! Air quality warnings and cycling. *Resource and Energy Economics, 49*, 165-185. doi:10.1016/j.reseneeco.2017.05.004

Sass, V., Kravitz-Wirtz, N., Karceski, S. M., Hajat, A., Crowder, K., & Takeuchi, D. (2017). The effects of air pollution on individual psychological distress. *Health & Place, 48*, 72-79. doi:10.1016/j.healthplace.2017.09.006

Schwartz, A. (1973). Interpreting the Effect of Distance on Migration. *Journal of Political Economy, 81*(5), 1153-1169. doi:10.1086/260111

Van Khuc, Q., Phu, T. V., & Luu, P. (2020). Dataset on the Hanoian suburbanites' perception and mitigation strategies towards air pollution. *Data in Brief, 33*, 106414. doi:https://doi.org/10.1016/j.dib.2020.106414

Vehtari, A., Gelman, A., & Gabry, J. (2017). Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. *Statistics and Computing, 27*(5), 1413-1432. doi:10.1007/s11222-016-9696-4

Vert, C., Sánchez-Benavides, G., Martínez, D., Gotsens, X., Gramunt, N., Cirach, M., . . . Gascon, M. (2017). Effect of long-term exposure to air pollution on anxiety and depression in adults: A cross-sectional study. *International Journal of Hygiene and Environmental Health, 220*(6), 1074-1080. doi:10.1016/j.ijheh.2017.06.009

Vuong, Q.-H. (2016). Global Mindset as the Integration of Emerging Socio-Cultural Values Through Mindsponge Processes: A Transition Economy Perspective. In J. Kuada (Ed.), *Global Mindsets: Exploration and Perspectives* (pp. 109-126): Routledge.

Vuong, Q.-H. (2020). Reform retractions to make them more transparent. *Nature, 582*, 149. doi:10.1038/d41586-020-01694-x

Vuong, Q.-H. (2021). Western monopoly of climate science is creating an eco-deficit culture. *Economy, Land & Climate Insight*.

Vuong, Q.-H., Ho, M.-T., Nguyen, H.-K. T., & Nguyen, M.-H. (2019). The trilemma of sustainable industrial growth: Evidence from a piloting OECD's Green city. *Palgrave Communications, 5*, 156. doi:10.1057/s41599-019-0369-8

Vuong, Q.-H., La, V.-P., Ho, M.-T., Trang, V. T., & Ho, M. T. (2020). Identifying the moral-practical gaps in corporate social responsibility missions of Vietnamese firms: an event-

based analysis of sustainability feasibility. *Corporate Social Responsibility and Environmental Management*. doi:https://doi.org/10.1002/csr.2029
Vuong, Q.-H., La, V.-P., Nguyen, M.-H., Ho, M.-T., Ho, M.-T., & Mantello, P. (2020). Improving Bayesian statistics understanding in the age of Big Data with the bayesvl R package. *Software Impacts, 4*, 100016. doi:10.1016/j.simpa.2020.100016
Vuong, Q.-H., La, V.-P., Nguyen, M.-H., Ho, M.-T., Tran, T., & Ho, M.-T. (2020). Bayesian analysis for social data: A step-by-step protocol and interpretation. *MethodsX, 7*, 100924. doi:10.1016/j.mex.2020.100924
Vuong, Q.-H., Le, T.-T., Nguyen, Q.-L., Nguyen, Q.-T., & Nguyen, M.-H. (2021a). Escaping from air pollution: The psychological process of domestic migration intention among urban people. *arXiv preprint*, arXiv:2108.00497.
Vuong, Q.-H., Le, T.-T., Nguyen, Q.-L., Nguyen, T. Q., & Nguyen, M.-H. (2021b). *Escaping from air pollution: The psychological process of domestic migration intention among urban people*. Retrieved from https://osf.io/5pv7y
Vuong, Q.-H., & Napier, N. K. (2015). Acculturation and global mindsponge: an emerging market perspective. *International Journal of Intercultural Relations, 49*, 354-367.
Vuong, Q. H. (2021). The semiconducting principle of monetary and environmental values exchange. *Economics and Business Letters, 10*(3), 284-290. doi:10.17811/ebl.10.3.2021.284-290
Ward, C., Bochner, S., & Furnham, A. (2020). *The Psychology of Culture Shock* (2 ed.): Routledge.
Wendling, Z. A., Emerson, J. W., de Sherbinin, A., Esty, D. C., & al., e. (2020). *2020 Environmental Performance Index*. Retrieved from New Haven, CT:
Wolpert, J. (1966). Migration as an Adjustment to Environmental Stress. *Journal of Social Issues, 22*(4), 92-102. doi:10.1111/j.1540-4560.1966.tb00552.x
Zivin, J. G., & Neidell, M. (2009). Days of haze: Environmental information disclosure and intertemporal avoidance behavior. *Journal of Environmental Economics and Management, 58*(2), 119-128. doi:10.1016/j.jeem.2009.03.001