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Air pollution and perception-based averting behaviour in the Jinchuan mining area, China

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Abstract

This paper presents a simultaneous equation, knowledge and perception-based averting behavior model of health risk caused by air pollution, with application to the Jinchuan mining area, China. Three types of averting behavior are distinguished: (a) purchases of purifying equipment, plants, or masks; (b) purchases of preventive or curing medication or food; and (c) adjustment of daily outdoor activities. Two types of perceived health risk are distinguished: (a) risk due to the intensity of exposure and (b) risk caused by the hazardousness of pollutants. The estimations show that an increase in perceived air pollution of two or more days a week leads to a restriction of outdoor activities of approximately 90 min per person per week. Another result is that the average annual household expenditure on air filters, foods, or medicines is 206.25 CNY (US\$ 31.73) to prevent the hazardousness of air pollution. The total willingness to pay for air quality improvement is 2.95% of annual net household income. Because air quality improving investments can only be implemented in the medium or long run, daily disclosure of air quality is an adequate short-run policy handle to assist residents to take the right kind and level of risk-reducing actions.

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1 Introduction

During the last three decades, China has experienced rapid economic growth and become an engine of the global economy. However, its rapid growth has also resulted in serious air pollution. For example, suspended particulate matter (PM) and sulfur dioxide (SO₂) are far above the World Health Organization's Air Quality Guidelines in most Chinese cities (Chen et al. 2017a, b). Based on air pollution data from 2013 to 2015, Barwick et al. (2018) estimated that a 10 μ g/m3 increase in PM2.5 concentration in China resulted in a 60 billion yuan (\$9 billion) increase in annual health spending by the Chinese population.

The Jinchuan mining area (abbreviated as Jinchuan), which is part of Jinchang city, is located in the northeast of the Hexi Corridor in Gansu Province. The total area of Jinchuan is 3370 square kilometers, and the total population in 2020 was 314,600. Jinchuan's economy is dominated by mining and processing of nickel, which have substantially contributed to its local economic development. In particular, 50% of Jinchuan's working population is employed by the nickel industry. However, these industries have also caused serious environmental issues, especially air pollution. Jinchuan is one of the ten cities in China most seriously affected by air pollution (Ding et al. 2018; Lan 2013; Wei 2008). Suspended particles, SO₂, chlorine gas and carbon dioxide are the main health-related pollutants (Huang et al. 2009; Lan 2013; Wen et al. 2018).

Many studies have been conducted on the link between air pollution exposure and behavioral responses, notably the trade-off between the cost of averting behavior and the benefits of reducing exposure in a bid to reveal people's preference for improving air quality. Examples of this literature are on installing air filters indoors (Bresnahan et al. 1997; Ito and Zhang 2020), wearing masks outdoors (Zhang and Mu 2018), adjusting or cancelling outdoor activities (Bresnahan 1997; Neidell 2009; Zivin and Neidell 2009), taking preventive or curing medication or food (Deschenes et al. 2012), migration (Banzhaf and Walsh 2008; Chen et al. 2017a, b), and choosing travel modes (Dirks et al. 2012; Kingham et al. 2013).

The objective of this paper is to analyze the responses of the inhabitants of Jinchuan to the health risks related to air pollution in their region and to estimate their preference for air quality improvement in terms of willingness to pay (WTP). To this end, we apply the household production function approach, introduced by Grossman (1972) and Parente et al. (2000), particularly the health-related averting behavior model.

Traditionally, the relationship between the costs of averting actions and socioeconomic characteristics (e.g., age and education) is applied to explain averting behavior. However, many researchers have pointed out that sociopsychological factors, particularly knowledge and perception, are also needed for adequate modeling of (averting) behavior (Folmer 2009; Folmer and Johansson-Stenman 2011; Menon et al. 2008; Li and Hu 2018; Tan and Xu 2019).¹ For example, Folmer (2009) argued

¹ Pattanayak and Pfaff (2009), among others, showed that social and psychological factors can be included in traditional household production functions.

that the omission of sociopsychological factors leads to model under-specification and thus to biased estimators of all the model coefficients, if the omitted systematic explanatory variables are correlated with an included explanatory variable and the explanatory variables are mutually correlated - which is virtually always the case in the social sciences, including (environmental) regional science.

This paper presents an extension of the household production function model, specifically, the averting behavior model (Lloyd-Smith et al. 2018) extended with sociopsychological factors. The model is called the Perception-based Averting Behavior Model (PABM). The paper furthermore analyzes various types of averting behavior to reduce perceived health risk and presents a framework to estimate the WTP for health risk reduction. Finally, it presents an application of the model to Jinchuan city.

The paper is organized as follows Sect 2 outlines the perception-based averting behavior model (PABM). Section 3 briefly summarizes the methodology (structural equations model with latent variables (SEM)) and Sect. 4 describes the survey, data, and empirical results. Section 5 presents the conclusions and policy recommendations.

2 The perception-based averting behaviour model (PABM)

Before presenting the conceptual model, we point to the difference between objective risk and subjective risk. The former is based on a physical measurement (Stanek et al. 2011; Henschel et al. 2013), as of the PM2.5 concentration in the air or the physical impacts on the functioning of the lungs. Subjective risk is the personal interpretation of the physical measure, for instance, the perceived concentration of PM2.5 or the expected or perceived impacts on the functioning of the lungs. Objective and subjective risk can coincide but can also differ (Shaw and Woodward 2008; Schubert and Brück 2014; Mrkva et al. 2021). In the social sciences including averting behavior analysis, subjective risk is the decisive factor (Zhou et al. 2020; Zhang et al. 2021). Solely relying on objective risk and ignorance of subjective risk is likely to give a distorted picture of the phenomenon at hand and biased estimators of its determinants or impacts (Um et al. 2002; Nauges and Van Den Berg 2009; Richardson et al. 2012; Li et al. 2014; Lloyd-Smith; et al., 2018;). Specifically, laboratory experiments have frequently indicated that individuals tend to underestimate objective high-risk events and overestimate objective small-risk events (Hengen and Alpers 2019; Botzen et al. 2015).

Below, we develop the PABM and estimate it for Jinchuan. We present the definitions of the variables and discuss the relationships among them based on a literature review and consultations with experts on environmental problems in Jinchuan. Before going into detail, we note that because the literature on the relationship between averting behavior and perceived health risk caused by air pollution is limited, the scope of the literature review is expanded by also including research on the relationship between averting behavior and other forms of environmental risks besides air pollution. Because several of the relationships in Fig. 1 are well known or are intuitively clear, we focus on the less familiar aspects of the model.



Fig.1 Conceptual framework of the perception-based averting behaviour model (PABM). Notes: (1) Expected signs within brackets. (2) Variables in italics are latent variables. The indicators of the latent variables are not presented

The conceptual PABM is summarized in Fig. 1.

In the model and Fig. 1, latent variables (theoretical constructs) play an important role. Folmer and Oud (2008) defined latent variables as phenomena that are supposed to exist but cannot be directly observed. The reason that a latent variable is unobservable is that the underlying phenomenon does not directly correspond to anything that can be measured, or that observations of the phenomenon are contaminated with measurement errors. Well-known examples of latent variables are intelligence, welfare, quality of life, economic expectation, socioeconomic status.

A latent variable is given empirical meaning by means of one or more operational definitions (correspondence statements) connecting a latent variable with a set of observable variables (indicators) having direct empirical meaning. Hence, a latent is measured by observed indicators. For instance, intelligence is measured by psychological tests, welfare by inter alia income, environmental quality, health care and safety, socioeconomic status by inter alia personal income, schooling, profession. In addition to the indicators, the correspondence statements contain measurement errors.

An indicator can be taken as a latent variable by defining a direct correspondence between indicator and latent variable with measurement error equal to zero. Below, latent variables are presented in italics, indicators in straight letters. As in the case of indicators, latent variables can be endogenous or exogenous.

Below we first discuss the endogenous latent variables in the PABM and its indicators and next the exogenous latent and observable variables.

2.1 Endogenous latent variables

Figure 1 shows that there are three endogenous latent variables in the PABM: the core variable Averting Behavior and its determinants Perceived Health Risk and Environmental Knowledge. We first discuss the core variable and next its determinants.

2.1.1 Averting behavior (AVB)

We define AVB as defending oneself or one's family against air pollution by reducing exposure to air pollution or mitigating its adverse effects. We distinguish the following three types of observed averting behavior, which are taken as indicators of the latent variable AVB:

- Improving the quality of the air inhaled by installing mechanical air filters, growing air filtering plants at home, or wearing masks outdoors (Bresnaha et al. 1997; Richardson et al. 2012; Zhang and Mu 2018; Ito and Zhang 2020). This indicator is denoted as AVB1. It is measured as expenditure per household in CNY.
- Taking preventive or curing medication or food (Deschenes et al. 2012; Richardson et al. 2012). This indicator is denoted as AVB2 and measured as expenditure per household in CNY.
- Adjusting outdoor activities by limiting, rescheduling, or otherwise changing planned outdoor leisure activities and spending more time indoors (Bresnahan et al. 1997; Eiswerth et al. 2005; Neidell 2009; Zivin and Neidell 2009; An and Xiang 2015; Choi et al. 2019). This indicator is denoted as AVB3 and measured as hours per week.

2.1.2 Perceived health risk (PHR)

Following Menon et al. (2008) and Ferrer and Klein (2015), we define the latent variable PHR as the subjective likelihood (judgement) of the occurrence of a negative event related to the health of a person or a group of persons over a specified spell of time. PHR is assumed to have a positive impact on AVB. Support for this hypothesis is given by inter alia Tan and Xu (2019) and Pan et al. (2020). Tan and Xu (2019) found that people's risk perception of air pollution positively and significantly influenced their averting behavior (e.g., wearing face masks) in Beijing, China. Using a nationally representative survey of 603 rice farmers from seven major rice-producing provinces in China, Pan et al. (2020) found that farmers' perceptions of the risks posed by pesticides to human health significantly decreased their pesticide expenditure. Support for the positive impact of PHR on AVB can also be found in Sullivan-Wileya and Gianottic (2017), Dryhurst et al. (2020) and Liu et al. (2021). We measure PHR using five indicators (Fig. 2). We take PHR as an endogenous variable depending upon, among other things, Environmental knowledge (EK).



Fig. 2 Distribution of the indicators of Perceived health risk (PHR). Note: PHR1: What is the average number of days per week during the past year you perceived the air in Jinchuan to be polluted? PHR2: In my perception, Jinchuan's air pollution increases the possibility of suffering from respiratory illnesses. PHR3: In my perception, Jinchuan's air pollution increases the possibility of suffering from cardiovascular illnesses. PHR4: In my perception, Jinchuan's air pollution increases the possibility of suffering from cardiovascular illnesses. PHR4: In my perception, Jinchuan's air pollution increases the possibility of suffering from ung cancer. PHR5: In my perception, Jinchuan's air pollution increases the possibility of suffering from untimely death

2.1.3 Environmental knowledge (EK)

EK is defined as an individual's cumulative body of knowledge of the interdependence between humans or society and the natural environment (Berkes et al. 2000). Knowledge is generally considered a prerequisite for psychological factors such as valuation and attitude (Croy et al. 2010; Mohiuddin et al. 2018), and especially risk perception (Peters and Slovic 1996; Zhong et al. 2021).

We assume that EK positively affects PHR. Support for this hypothesis was provided by inter alia Chen and Liu (2021) found that Beijing residents' knowledge of air pollution significantly influenced their risk perception. In addition, Shi et al. (2016) found that higher levels of knowledge about the causes of climate change were associated with a heightened perception of the risks of climate change.

We also assume a reverse impact of PHR on EK in that PHR induces people to collect more information on the risk problem they are concerned about. Support for this hypothesis was provided by Zhong et al. (2021) who found that in a sample of COVID-19 patients in Wuhan, China, risk perception towards COVID-19 significantly influenced their collection of knowledge of the disease. Hence, we postulate a bidirectional relationship between EK and PHR. We assume no direct impact of EK on ABV but just an indirect impact via PHR (Iorfa et al. 2020). We measure EK using eight indicators (Fig. 3).



Air pollution and perception-based averting behaviour in...

Fig. 3 Distribution of the indicators of environmental knowledge (EK). Note: EK1: Do you acknowledge that Jinchuan suffers from air pollution? EK2: Do you acknowledge that Jinchuan suffers from industrial solid waste? EK3: Do you acknowledge that Jinchuan suffers from water pollution? EK4: Do you acknowledge that environmental issues in Jinchuan are mainly caused by local industrial activities? EK5: Do you acknowledge that sulfur dioxide is one of the main air pollutants in Jinchuan? EK6: Do you acknowledge that carbon dioxide is one of the main air pollutants in Jinchuan? EK7: Do you acknowledge that carbon dioxide is one of the main air pollutants in Jinchuan? EK8: Do you acknowledge that chlorine gas is one of the main air pollutants in Jinchuan?

2.2 Exogenous latent variable

2.2.1 Socioeconomic status (SES)

SES is a latent variable measured via the indicators Income and Education (see Assari et al. (2018) and Mackay (2006) for an overview and details). Specifically, people with higher SES commonly have higher educational levels and earn more than individuals with lower SES (Smedley and Syme 2001; Niessen et al. 2018). We assume that SES has a positive impact on AVB. Tan and Xu (2019) support this assumption. We also postulate that SES positively impacts EK and PHR. That is, people with higher SES commonly have a better understanding of environmental issues and can better assess risks (Pu et al. 2019). Education is measured as the highest level of education obtained and Income as family income after taxes (Table 1).

	Samp	le			Population
Variables	Min	Max	Mean	S.D	Mean
Age (AGE)	21	78	44.11	11.4	37.54
Family size (FS)	1	6	2.95	0.78	2.58
Family health experience (FHE)	0	1	0.33	0.48	
Averting behaviour (AVB)					
AVB1 (CNY per household per year)	0	2100	177.59	241.79	
AVB2 (CNY per household per year)	0	1500	28.66	121.88	
AVB3 (Hours per week per person)	0	27	8.97	7.54	
		Sample	Population	Sample	
Education (EDU)		%		Net household inc (CNY per mont	come h)
Primary school		6.30	22.78	1000-2000	4.70%
Middle school		23.60	38.89	2000-3000	15.30%
High school		25.30	22.47	3000-4000	18.30%
Vocational		25.30	9.57	4000-5000	19.10%
Bachelor's degree		19.10	6.00	5000-6000	20.90%
Master's degree		0.40	0.30	6000-7000	13.00%
Proximity to the pollution source (PPS)		%		7000-8000	3.70%
Nearby smelting plants, severe air pollution (SAP)	on	29.60	29.60	8000–9000	1.80%
Medium air pollution (MAP)		29.80	29.80	More than 10000	2.00%
Far away from smelting plants, light air p (LAP, reference case)	ollution	40.60	40.60		
Work environment (WE)		%			
Non-JMC employee (reference case)		59.55	85.36		
Miners and smelter workers of JMC (MS)	18.18	6.86		
JMC employee, but not miner or smelter (NMS)	worker	22.27	7.88		

 Table 1 Descriptive statistics of the sample and the population in 2012

(1)The population statistics on Family health experience and the indicators of Averting behavior (AVB) are not available. (2) The population distribution of Net household income is not available. (3) AVB1: Annual household expenditure on air filters and plants at home and face mask. AVB2: Annual household expenditure on special foods, medicines or seeing doctors. AVB3: Reduction of outdoor activities (hours per week) including limited, rescheduled, or otherwise postponed planned leisure time. Family size: number of family members living in the same house. Family health experience:1 if the respondent or one or more of the family members has/have been hospitalized for cardiovascular diseases (hypertension, heart attack, chest pain, arrhythmia or miocardial infraction) or respiratory diseases (upper respiratory tract infection, bronchitis, pneumonia, asthma, or lung cancer), 0 otherwise. (4) The descriptive statistics of Perceived health risk (PHR) and Environmental knowledge (EK) are presented in the Figs. 2 and 3, respectively

2.3 Directly observed explanatory variables

2.3.1 Age

In the literature review, we found substantial empirical evidence that Age impacts AVB (Mansfield et al. 2006; Vásquez and Espaillat 2016). However, there is uncertainty about its sign (Xu et al. 2017; Barnes et al.2004; Tan and Xu.2019). Choi et al. (2021) and Eiswerth et al. (2005) found positive impacts whereas Chakrabarti et al. (2009) and Talberth et al. (2006) found negative impacts. Given these opposing outcomes, we leave the sign of the impact of Age on AVB an open question. Fountain et al. (2019) argued that older individuals commonly have more knowledge of and experience with local problems including environmental problems (Teo et al. 2018), Hence, we assume that Age positively influences EK. We expect Age to indirectly impact PHR via EK.

2.3.2 Family size (FS)

There is empirical evidence that FS impacts AVB, but the expected impact is ambiguous. For instance, Vásquez (2014) and Talberth et al. (2006) found positive and negative impacts, respectively. Hence, we do not postulate the sign of the relationship. We also include FS in the PHR equation. The rationale is that a larger family has a greater capacity to absorb risks. For instance, a larger family has more options for burden sharing in case of illness implying a positive sign (Koos 2018). At the same time, a larger family carries a bigger risk implying a negative sign (Amaefula et al. 2012). Consequently, we do not hypothesize the sign of the relationship. We define FS as the number of family members who live in the same house (Table 1).

2.3.3 Proximity to the pollution source (PPS)²

The concentration of air pollutants decreases with distance from the source (smelting plant). Therefore, people who live close to a smelting plant are more susceptible to illnesses and tend to be more likely to take averting actions than those who live farther away. Devi et al. (2010) support this assumption. For the same reason, we hypothesize that PPS negatively influences PHR. Signorino (2012) and Muindi et al. (2014) provided evidence for this assumption. As proximity to the pollution source implies intensity of air pollution, we distinguish three categories: (a) serious air pollution (SAP), (b) medium air pollution (MAP), and (c) light air pollution (LAP).

² Housing allocation in Jinchuan is not based on supply and demand but managed by the local government and the mining company. The latter allots relatively cheap housing to its employees (source: private communication with local administrators). Thus, proximity to the pollution source is an exogenous variable in this paper.

2.3.4 Family health experience (FHE)

People who have experienced adverse health effects from air pollution are assumed to take more precautions to protect themselves and their family members than those who did not have had such experiences. Therefore, we expect such individuals to take more averting actions. Khan (2012) and Cui and Han (2019) support this hypothesis. Following Garrido et al. (2018) we also postulate a positive impact of FHE on PHR. We measure FHE by means of a dichotomous variable that takes the value 1 if the respondent or one or more of the respondent's family members have been hospitalized for cardiovascular or respiratory diseases, and 0 otherwise (see Table 1).

2.3.5 Work environment (WE)

Because the Jinchuan mining company (JMC) is the source of Jinchuan's environmental issues, we expect JMC employees to have better knowledge of Jinchuan's environmental issues than non-JMC individuals. The reason is that JMC employees, especially miners and smelter workers, are more knowledgeable about the inputs and outputs of the smelting process than non-JMC individuals. We distinguish three WE categories: (1) MS (miners and smelter workers of JMC); (2) NMS (people who are JMC employees but not miners or smelter workers); and (3) NMC (non-JMC workers), which is the base case. We hypothesize an indirect impact of WE on AVB via EK and PHR.

3 Methodology (SEM)

A basic feature of the conceptual model depicted in Fig. 1 is that there are several direct and indirect paths from socio-economic and demographic variables to EK, PHR and AVB. To capture the direct and indirect paths as well as the cycles in the conceptual model, we need simultaneous-equations models (e.g. Greene 2003; Bollen and Noble 2011). Another feature of the conceptual model is that it contains both observed and latent variables within the same model framework. Both features of the conceptual model can be handled by a structural equation model with latent variables (SEM) (Bollen and Noble 2011).³

A SEM is made up of three sub-models: two measurement models and the structural model (Jöreskog and Sörbom 1996; Bollen and Noble 2011). Specifically:

$$\mathbf{y} = \mathbf{\Lambda}_{\mathbf{y}} \mathbf{\eta} + \mathbf{\varepsilon}$$
 with $\mathbf{cov}(\mathbf{\varepsilon}) = \boldsymbol{\Theta}_{\mathbf{\varepsilon}}$ (1)

³ SEMs are relatively new in (environmental) regional science. We refer to Folmer and Oud (2008) who introduced latent variables in a spatial dependence model and to Tang et al. (2013), Tang and Folmer (2016) and Ren and Folmer (2017) for applications.

$$\mathbf{x} = \boldsymbol{\Lambda}_{x}\boldsymbol{\xi} + \boldsymbol{\delta} \quad \text{with} \quad \mathbf{cov}(\boldsymbol{\delta}) = \boldsymbol{\Theta}_{\boldsymbol{\delta}}$$
(2)

$$\eta = \mathbf{B}\eta + \Gamma\xi + \zeta \quad \text{with} \quad \mathbf{cov}(\xi) = \boldsymbol{\Phi}, \mathbf{cov}(\zeta) = \boldsymbol{\Psi}$$
 (3)

Equations (1) and (2) are the measurement models describing the relations between the latent variables and their indicators. That is, the measurement models contain the operational definitions (correspondence statements) of the latent variables. Specifically, **y** and **x** are (p×1) and (q×1) vectors of observed endogenous and exogenous variables, respectively, and **η** and ξ (m×1) and (n×1) vectors of latent endogenous and latent exogenous variables, respectively. Λ_y is a (p×m) matrix of loadings (regression coefficients) of **y** on **η**; Λ_x a (q×n) matrix with the loadings of **x** on ξ . In addition, Θ_{ϵ} (p×p) and Θ_{δ} (q×q) are covariance matrices of the (p×1) vector ϵ and (q×1) vector δ which are the measurement errors of **y** and **x**, respectively. Note that directly observed variables can be included in the structural model by specifying an identity relationship in the measurement model between a latent variable and its indicator and fixing the measurement error at zero.

Equation (3) is the structural model which specifies the relationships between the latent variables. **B** is an $(m \times m)$ matrix that contains the structural relationships among the latent endogenous variables η , Γ an $(m \times n)$ matrix of the impacts of the exogenous latent variables on the endogenous latent variables, and ζ a random $(p \times 1)$ vector of errors with $(p \times p)$ covariance matrix Ψ . The covariance matrix of ξ is Φ $(n \times n)$.⁴ For details on identification, estimation, testing and model modification of a SEM, we refer to Bollen and Noble (2011)

The use of SEM allows a closer correspondence between theory (which is formulated in terms of theoretical constructs) and empirics (which is based on observed variables) (Folmer and Oud 2008). It furthermore reduces attenuation bias (bias towards zero) in the structural model because the measurement errors of the explanatory variables are purged of the true latent variables in the measurement model (2). Finally, the use of SEM reduces multi-collinearity because strongly correlated observed variables are commonly linked to a smaller number (usually one) of latent variable(s) in the measurement model. In the structural model, the latent variables are used rather than the observed variables, hence the reduction of multicollinearity (Van Dijk and Folmer 1986).

In terms of Eqs. (1–3), the conceptual PABM (Fig. 1) reads as follows:

3.1 Measurement models

Endogenous latent variables measurement model: Equation (1)

$$\mathbf{y}_{[16]} = \mathbf{\Lambda}_{\mathbf{y}[16\times3]} \times \boldsymbol{\eta}_{[3]} \boldsymbol{\varepsilon}_{[16]}$$

⁴ It is possible to include intercepts in the measurement models and structural model. However, in the application we standardize the variables implying that there are no intercepts.

$$\begin{bmatrix} AVB1\\ \vdots\\ AVB3\\ PHR1\\ \vdots\\ PHR5\\ EK1\\ \vdots\\ EK8 \end{bmatrix} = \begin{bmatrix} \lambda_{11}^{y} & 0 & 0\\ \lambda_{21}^{y} & \vdots & \vdots\\ \lambda_{31}^{y} & 0 & 0\\ 0 & \lambda_{42}^{y} & 0\\ 0 & \lambda_{52}^{y} & 0\\ \vdots & \vdots & \vdots\\ 0 & \lambda_{52}^{y} & 0\\ \vdots & \vdots\\ 0 & \lambda_{82}^{y} & 0\\ 0 & 0 & \lambda_{93}^{y}\\ 0 & 0 & \lambda_{103}^{y}\\ \vdots & \vdots & \vdots\\ 0 & 0 & \lambda_{163}^{y} \end{bmatrix} \times \begin{bmatrix} AVB\\ PHR\\ EK \end{bmatrix} + \begin{bmatrix} \varepsilon_{1}\\ \vdots\\ \varepsilon_{3}\\ \varepsilon_{4}\\ \vdots\\ \varepsilon_{8}\\ \varepsilon_{9}\\ \vdots\\ \varepsilon_{16} \end{bmatrix}$$
(4)

Exogenous latent variables measurement model: Equation (2)

$$\mathbf{x}_{[9]} = \boldsymbol{\Lambda}_{x[9\times8]} \times \boldsymbol{\xi}_{[8]} + \boldsymbol{\delta}_{[9]}$$

$$\begin{bmatrix} \text{EDU} \\ \text{IN} \\ \text{FS} \\ \text{AGE} \\ \text{FHE} \\ \text{FHE} \\ \text{SAP} \\ \text{NMS} \\ \text{MS} \end{bmatrix} = \begin{bmatrix} \lambda_{11}^{x} & 0 & 0 & 0 & 0 & 0 & 0 \\ \lambda_{21}^{x} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} \text{SES} \\ \text{FS} \\ \text{AGE} \\ \text{FHE} \\ \text{MAP} \\ \text{SAP} \\ \text{NMS} \\ \text{MS} \end{bmatrix} + \begin{bmatrix} \delta_{1} \\ \delta_{2} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$
(5)

The structural model: Equation (3)

$$\mathbf{\eta}_{[3]} = \mathbf{B}_{[3\times3]} \times \mathbf{\eta}_{[3]} + \mathbf{\Gamma}_{[3\times8]} \times \mathbf{\xi}_{[8]} + \mathbf{\zeta}_{[3]}$$

$$\begin{bmatrix} AVB \\ PHR \\ EK \end{bmatrix} = \begin{bmatrix} 0 & \beta_{12} & 0 \\ 0 & 0 & \beta_{23} \\ 0 & \beta_{32} & 0 \end{bmatrix} \times \begin{bmatrix} AVB \\ PHR \\ EK \end{bmatrix} + \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{14} & \gamma_{15} & \gamma_{16} & 0 & 0 \\ \gamma_{21} & \gamma_{22} & 0 & \gamma_{24} & \gamma_{25} & \gamma_{26} & 0 & 0 \\ \gamma_{31} & 0 & \gamma_{3} & 0 & 0 & 0 & \gamma_{37} & \gamma_{38} \end{bmatrix} \times \begin{bmatrix} SES \\ FS \\ AGE \\ FHE \\ MAP \\ SAP \\ NMS \\ MS \end{bmatrix} + \begin{bmatrix} \zeta_{1} \\ \zeta_{2} \\ \zeta_{3} \end{bmatrix}$$
(6)

4 Empirical results

4.1 Survey and data collection

The data analyzed in this paper was obtained from a household survey conducted in Jinchuan in 2012. A stratified random sample of 800 respondents, aged between 21 and 78, was drawn. Jinchuan was divided into three sub-areas based on the level of air pollution (corresponding to the distance from the smelting plant): severely polluted, moderately polluted, and lightly polluted (JEQMR 2011; Wei 2008). The respondents in each area were randomly selected in proportion to its total population size. Specifically, per one hundred households in the population, 1–2 households were randomly selected giving a total sample size of 800. Respondents were family heads, usually husbands, with a "hukou" (i.e., a permanent residence permit), who had lived in Jinchuan for at least ten years.

Theoretically, there is a risk of sample selection bias in that only inhabitants are included in the sample whereas people who left the area for environmental concerns are not taken into account. However, as is usually the case in China (Aunan and Wang 2014; Du et al. 2005), people merely leave their home area for reasons of employment, marriage, or education rather than for (air) pollution. So, if there was outmigration for environmental reasons, it was part of a combination of motives. To get insight into the weight of air pollution in the decision to leave, a separate survey among outmigrants would be needed, which was beyond the scope of the present study. The upshot is that the estimated willingness to pay is a lower bound because the people who also left for environmental reasons were not included in the survey.

Because the questionnaire was eight pages long, face-to-face interviews were conducted. A group of college students at Gansu Non-ferrous Metallurgy College in Jinchuan who understood the environmental issues in Jinchuan and spoke the local language well was selected as interviewers and trained accordingly. Moreover, a pilot survey was carried out on the basis of which the questionnaire was adjusted, corrected, and reworded. The response rate was about 90% which is high, but not uncommon, in China (Holtom et al. 2022).

The questionnaire contained the following guarantees to achieve a close correspondence between what respondents said and what they do or think. First, the questionnaire did not contain questions about sensitive issues such as drug use, sexual behaviors, or voting, which are common reasons for people to answer untruthfully for privacy reasons (Quatember 2019). All the questions related to fully accepted behaviors. Second, there were no knowledge barriers to understanding or answering the questions; they were simple and straightforward. Moreover, the responses were pre-coded. Finally, for data collection, we used face-to-face interviews with well-trained interviewers who understood the environmental issues in Jinchuan and the local language well.

4.2 Descriptive statistics

Of the 800 completed questionnaires, 41 (5.12%) were rejected because they were incomplete. There was no evidence of non-random dropout. Descriptive statistics are presented in Table 1 and Figs. 2 and 3. The differences between the sample and the population statistics in Table 1 with respect to age, income, and education are due to the fact that the sample was drawn from the sub-population of heads of households aged 21–78. Below we only discuss the indicators of Perceived health risk (PHR) and Environmental knowledge (EK) as the other descriptive statistics are self-evident.

Five indicators were used to measure PHR. First, the question (PHR1): What is the average number of days per week you perceived the air in Jinchuan to be polluted during the past year? Fig. 2 shows that the percentages of respondents who answered four or more and zero or one were 18.30% and 19.60%, respectively. The majority (62.1%) answered two or three. Second, four major types of illnesses were presented to the respondents to measure their perception that Jinchuan's air pollution increases the probability of suffering from four well-known health problems. A five-point scale was used with 1 indicating "strong negative perception" and 5 "strong positive perception." The results show that respiratory illnesses (95.90%) were most frequently mentioned, followed by lung cancer (83.60%), cardiovascular illnesses (75.00%), and death (73.10%).

We examined the respondents' knowledge of environmental issues (EK) in Jinchuan using eight indicators (Fig. 3). Each indicator was measured on a fivepoint scale ranging from 1 (certainly not) to 5 (certainly). The first four indicators (EK1–EK4) tested the respondents' knowledge of Jinchuan's general environmental issues and their causes. Figure 3 shows that over 80.00% of the respondents "fully acknowledged" or "acknowledged" that air pollution, industrial solid waste, and water pollution were serious environmental issues in Jinchuan. Moreover, 93.20% "acknowledged" or "fully acknowledged" that Jinchuan's environmental problems were mainly caused by local industrial activities (EK4). The final four indicators (EK5–EK8) specified the main air pollutants. Figure 3 shows that over 55.00% of the respondents either "fully acknowledged" or "acknowledged" that chlorine gas, SO₂, suspended particles and carbon dioxide were the main pollutants.

4.3 The estimated SEM⁵

As described in the previous section, several observed variables, notably the indicators of PHR and EK, are ordinal or dichotomous. Moreover, the indicators of EK are highly skewed and non-normally distributed (Fig. 3). Therefore, WLS based on the matrix of polychoric correlations was employed to estimate models (4)-(6).⁶ The SEM estimates presented below are standardized coefficients which present the standard deviation change in a dependent variable due to a standard deviation change in an explanatory variable. Standardized coefficients are directly comparable because the scales of the explanatory variables are irrelevant.

As a first step, we estimated the full conceptual model presented in Sect. 2 and the Eqs. (4–6). It is presented in Appendix 1. In the Initial Measurement Model (Table 5), the *R*-square of AVB3 was very low (0.01). Following Bollen (1989), we took this as an indication that ABV1 and ABV2 on the one hand, and ABV3 on the other, measure different dimensions of AVB.⁷ In addition to the *R*-squares, there are substantive arguments for this interpretation. Specifically, whereas AVB1 and AVB2 relate to expenditures (on masks, purifying equipment, plants, food or medicine), AVB3 measures activities (reducing outdoor activities). Therefore, we split the latent variable AVB into a latent variable Expenditure measured by the indicators AVB1 and AVB2, and a latent variable Reduction measured by AVB3.

The *R*-square of PHR1 was also very low (0.02, Appendix Table 5) indicating that it measures a different dimension of PHR than its other indicators. Particularly, it reflects a respondent's concern about exposure to air pollution (average number of days per week you perceived the air in Jinchuan to be polluted) whereas the other indicators measure perceived impacts. For example, PHR2 measures the perceived risk of suffering from respiratory illnesses. Accordingly, we split the latent variable PHR into perceived health risk caused by exposure (Exposure), measured by PHR1, and perceived health risk caused by the hazardousness of pollutants (Hazardousness), measured by PHR2–5. Note that this split is in line with Sjöberg et al.'s (2004) and Egondi et al.'s (2013) substantive arguments.

In the Initial Structural Model, several explanatory variables of Expenditure and Reduction were highly insignificant. We deleted variables with insignificant coefficients in a stepwise procedure starting with the one with the largest *p*-value greater than 10% (stepwise backward elimination). However, we retained some of the insignificant variables for substantive reasons. This gave the Final Model, which we will discuss next.

⁵ The model was estimated using the software package LISREL 8 (Jöreskog and Sörbom, 1996). Additional output, including the variance–covariance matrices of the measurement models and the matrix of modification indices, is available upon request from the first author.

⁶ Note that latent variables are unobservable and thus have no measurement scales. To render the model identified and to make the parameters interpretable, we assigned measurement scales to the latent variables by fixing their variances (at 1). See Bollen and Noble (2011) for details.

⁷ Note that the R-square of AVB2 is a border case.

Latent variables	Indicator	Coefficient	Standard error	R^2
Endogenous latent variables				
Expenditure	AVB1	0.36	0.12	0.13
	AVB2	0.28	0.09	0.08
Reduction	AVB3	1.00	0.02	1.00
Exposure	PHR1	1.00	0.02	1.00
Hazardousness	PHR2	0.60	0.03	0.36
	PHR3	0.52	0.03	0.28
	PHR4	0.62	0.03	0.38
	PHR5	0.55	0.03	0.30
Environmental knowledge	EK1	0.51	0.04	0.26
	EK2	0.49	0.03	0.24
	EK3	0.42	0.03	0.18
	EK4	0.46	0.04	0.22
	EK5	0.55	0.04	0.30
	EK5	0.49	0.03	0.24
	EK7	0.34	0.03	0.12
	EK8	0.43	0.03	0.19
Exogenous latent variable				
Socioeconomic Status	Education	0.49	0.05	0.24
	Income	0.45	0.04	0.21

Table 2 Final measurement models

The variables Age, Family size, Health experience, Proximity to the pollution source and Work environment are directly observed latent variables implying an identity relationship between latent variable and indicator. These variables are not included in Table 2

The goodness-of-fit indices of the Final Model are satisfactory. They all meet their cutoff values that are given in brackets. Specifically: $\chi^2/DF=2.22$ (<3), goodness-of-fit index = 0.98 (>0.90), adjusted goodness-of-fit index = 0.97 (>0.90), standard-ized root mean square residual = 0.03(<0.08), root mean square error of approximation = 0.41 (<0.05)). See Bollen and Noble (2011) and Byrne (2013) for details.

The Final Measurement models are presented in Table 2. For each indicator, we present its loading, standard error, and R-square. Table 2 indicates that the loadings of all indicators of the latent endogenous variables are significant at 1%. Hence, the measurement of the endogenous latent variables is adequate. The exogenous latent variable SES is adequately measured by its indicators Income and Education, as shown by their significant loadings and R-square.

The structural model is presented in Table 3. It shows that Exposure positively and significantly induces Reduction.⁸ That is, the more days a week an individual

⁸ The R-squares of the *Reduction* and *Exposure* equations are low. However, low R-squares are quite common in cross-section analyses in the social sciences. Although a low R-square indicates that other factors than the ones included in the model affect the dependent variable, this does not necessarily mean poor estimation of the *ceteris paribus* relationships between the dependent variable and the explanatory variables (Wooldridge, 2012). That is, if the zero conditional mean assumption is met, then the estimator of the impacts of the explanatory variables on the dependent variable is unbiased.

Variables	Expenditure	Reduction	Exposure	Hazardousness	EK
Expenditure					
Reduction					
Exposure		0.20***			
		(0.06)			
Hazardousness	0.15				
	(0.11)				
Environmental knowledge (EK)			0.13***	0.69***	
			(0.03)	(0.09)	
Socioeconomic status (SES)	0.69***	0.03	0.05	0.10*	0.36***
	(0.49)	(0.03)	(0.04)	(0.08)	(0.07)
Age (AGE)					0.09***
					(0.03)
Family size (FS)				-0.08^{***}	
				(0.03)	
Family health experience (FHE)				0.05	
				(0.03)	
Medium air pollution (MAP)			0.09***	0.06	
			(0.03)	(0.04)	
Serious air pollution (SAP)			0.19***	0.05	
			(0.03)	(0.04)	
JMC employment not miner or smelter worker (NMS)					0.08 (0.05)
JMC miners and smelter workers (MS)					0.17***
					(0.04)
R^2	0.57	0.04	0.05	0.51	0.17

Table 3 Final structural equation model

Standard errors in parenthesis. Significance level: *, **and ***:10%, 5% and 1%, respectively

perceives the air to be polluted, the more he or she restricts outdoor activities. Apparently, Reduction is seen as an adequate response to Exposure because it immediately reduces perceived risk as a consequence of spending time outdoors. In addition, the instrument is easy to apply. The impact of Exposure on Expenditure was highly insignificant and was deleted. Apparently, Expenditure is not seen as a cure for Exposure. The intuition is that Exposure relates to outdoor air pollution which, at first instance, requires instantaneous protection. Expenditure on the other hand relates to purification of indoor air quality⁹ and to the long-term consequences of air

⁹ An exception is wearing masks. However, this type of prevention is so common that it is a part of everyone's daily outfit.

pollution. The latter is captured by Hazardousness which, as hypothesized in Sect. 2, positively affects Expenditure on plants, food and medicine.

EK positively and significantly influences both types of PHR. The reverse effect, however, was highly insignificant and not included in the Final Model. A possible explanation for the latter is that the suffocating and pungent odor related to the main air pollutants, particularly SO_2 and chlorine gas, are sufficient evidence of the health risks that one runs. The persistence of the odor renders further knowledge acquisition redundant.

In line with the conceptual model, SES positively and significantly influences Expenditure, whereas its impact on Reduction is positive, though marginally significant. This difference in outcome is due to the fact that the purchase of purification equipment, special food, or medicine requires financial outlays, whereas restricting outdoor leisure activities does not have financial implications. Moreover, Expenditure requires knowledge of the healing effects of medicines and food. The positive impact of SES on EK and Hazardousness supports the hypothesis that individuals with higher SES can acquire a better understanding of the nature of environmental issues and make a better judgment of the health risks caused by the main air pollutants in the Jinchuan area.

Apart from EK and SES, FS has a significant negative impact on Hazardousness indicating that there is a dampening of risk perception in larger families. SAP and MAP (Fig. 4) as consequences of the proximity to the pollution source (PPS) positively influence Exposure and Hazardousness, as hypothesized in Sect. 2, although the impact on Hazardousness is marginally significant. Hazardousness is also positively and significantly, though marginally, influenced by FHE indicating that a family's health experience tends to raise awareness of and increase concerns about the health risks correlated with air pollution.

The positive effect of Age on EK suggests that older individuals—who in virtually all cases have spent most of their lives in Jinchuan—have better knowledge of Jinchuan's environmental issues. EK was also positively and significantly affected by one's workplace. The same applies to Work Environment (WE). JMC employees not working in the mines or smelting plants and especially miners or smelters are knowledgeable about the production processes and its impacts on Jinchuan's environmental issues.

4.4 Indirect and total effects

Table 4 presents the standardized indirect and total effects of all endogenous and exogenous variables on all endogenous variables. An indirect effect is the effect of an endogenous or exogenous variable on an endogenous variable through intervening endogenous variables and the total effect is the sum of the direct and indirect effects (Bollen and Noble 2011).



Fig. 4 Heavily, moderately and lightly polluted areas of the Jinchuan mining area. Note: the dominant wind directions are from the east and south-east during summer and from the west and north-west during winter. *Source*: JEQMR (2011), Wei (2008) and Li et al. (2014)

	Total effects					Indirect effects				
Variables	Expenditure	Reduction	Exposure	Hazardousness	EK	Expenditure	Reduction	Exposure	Hazardousness	EK
Expenditure										
Reduction										
Exposure		0.20^{***}								
		(0.06)								
Hazardousness	0.15			,						
	(0.11)									
Environmental knowledge (EK)	0.10	0.03 **	0.13^{***}	0.69^{***}		0.10	0.03^{**}			
	(0.10)	(0.02)	(0.05)	(0.09)		(0.10)	(0.02)			
Socioeconomic Status (SES)	0.74***	0.05*	0.10^{***}	0.35***	0.36^{***}	0.05	0.02^{**}	0.05***	0.25***	
	(0.41)	(0.04)	(0.05)	(0.09)	(0.07)	(0.05)	(0.01)	(0.02)	(0.07)	
Age (AGE)	0.01	0.002*	0.01^{**}	0.06***	0.09***	0.01	0.002*	0.01^{**}	0.06***	
	(0.01)	0.001	(0.01)	(0.03)	(0.03)	(0.01)	(0.001)	(0.01)	(0.03)	
Family size (FS)	-0.01			-0.08^{***}		-0.01				
	(0.01)			(0.03)		(0.01)				
Family health experience (FHE)	0.01			0.05		0.01				
	(0.01)			(0.03)		(0.01)				
Medium air pollution (MAP)	0.01	0.02^{**}	***60.0	0.06		0.01	0.02^{**}			
	(0.01)	(0.01)	(0.03)	(0.04)		(0.01)	(0.01)			
Serious air pollution (SAP)	0.01	0.04^{**}	0.19^{***}	0.05		0.01	0.04^{***}			
	(0.01)	(0.01)	(0.03)	(0.04)		(0.01)	(0.01)			
JMC employment not miner or smelter worker	0.01	0.002	0.01	0.06	0.08	0.01	0.002	0.01	0.06	
(NMS)	(0.01)	(0.002)	(0.01)	(0.04)	(0.05)	(0.01)	(0.002)	(0.01)	(0.04)	
Miners and smelter workers of JMC (MS)	0.02	0.005*	0.02^{***}	0.12^{***}	0.17^{***}	0.02	0.002^{*}	0.02^{**}	0.12^{***}	
	(0.01)	(0.002)	(0.01)	(0.04)	(0.04)	(0.01)	(0.001)	(0.01)	(0.04)	
Standard errors in parenthesis. Significance	level: *, **and *	***:10%, 5%	and 1%							

Table 4 Total and indirect effects

Table 4 shows that SES has the largest positive total effect (0.74) on Expenditure, followed by Hazardousness, although the latter impact is marginally significant. The total effects of the other variables on Expenditure are insignificant. Exposure is the most important determinant of Reduction, with a total effect of 0.20. Next is SES (0.05). Although they have no direct effects on it, EK, Age, PPS, and WE also positively and significantly influence Reduction. EK, SES, and PPS are the most important determinants of Exposure. Age and WE also significantly and positively impact Exposure, but their total effects are small.

The most important determinant of Hazardousness is EK with a total effect of 0.69. The next important one is SES (0.35). Age and WE indirectly and significantly influence Hazardousness via EK. Serious (SAP) and medium (MAP) polluted areas also positively influence Hazardousness with total effects of 0.06 and 0.05, respectively, although they are marginally significant. FS and FHE impact Hazardousness with total effects of -0.08 and 0.05, respectively, although FHE's impact is marginally significant.

SES is the most important determinant of EK with a total effect of 0.36. Employees of JMC but not miners or smelter workers (NMS) and miners and smelters (MS) have better EK than individuals not affiliated with JMC. The total effects are 0.08 and 0.17, respectively. The total effect of NMS, however, is insignificant. The total effect of Age on EK is 0.09.

4.5 The willingness-to-pay (WTP) for improved air quality

The calculation of the WTP for improved air is based on the costs of the indicators of Reduction (AVB3) and Expenditure (AVB1 and AVB2). For the WTP measured by ABV1 and ABV2 we take the average expenditures from Table 1: 177.59 CNY and 28.66 CNY, respectively. The expenditure on purchasing air filters and face mask (AVB1) is much higher than the expenditure on medicines and food (AVB2). One reason for this is that AVB1 is believed to prevent the negative health impacts caused by air pollution (personal communication with the Jinchuan health authorities). In addition, most medication for JMC employees is available at low prices or for free because of JMC's subsidies (personal communications with representatives of the company).

As the latent explanatory variable Exposure is identical to its observed indicator PHR1, standard regression is applicable. Hence, we un-standardized the standardized structural coefficient and the dependent variable and regressor to find that two or more days of air pollution led to a reduction of outdoor activities (ABV3) of 1.51 h per week. If we value this outcome at the average hourly wage rate in Jinchuan (26.01 CNY per hour in 2012),¹⁰ we arrive at a loss of 39.22 CNY per week (26.01×1.51). For the average household of 2.95 people, this amounts to 115.71 CNY per household per week. As air pollution is concentrated in the period December–February this amounts to 12×115.71 CNY = 1388.52CNY per year.

The following observations apply. First, the welfare loss of 1388.52CNY is an upper bound because the reduced outdoor activities may be spent on valuable

¹⁰ Source: Jinchuan Statistical Yearbook (2011).

alternative indoor activities. On the other hand, air pollution also occurs outside the December–February period which also induces restrictions on outdoor activities. Secondly, we have taken the average hourly wage rate for each household member. Although the average hourly wage rate may on average apply to employed household members, it is unlikely that it also applies to unemployed household members, such as young children. This problem can be overcome by differentiating by type of household members.

The average WTP for improved air quality derived from all three indicators of AVB1–AVB3 is $\frac{1388.52+177.59+28.66}{54000} = 2.95\%$ of the average yearly net household income (54,000 CNY). This outcome is substantially larger than the WTP obtained by Murthy et al. (2003) who found that households in Delhi and Kolkata, India, were willing to pay 0.13% and 0.21%, respectively, of the average yearly household income to reduce the level of suspended PM to a safe level. However, the study by Murthy et al (2003) was substantially smaller in terms of pollutants considered and types of averting behavior analyzed.

To evaluate the WTP outcome for Jinchuan, it should be noted that Jinchuan is located in a peripheral, poor region of China with an average net household income of 54,000 CNY per year which is far below the national annual average of 68,000 CNY. Under these conditions, the WTP of 2.95% of average yearly net household income is an indication that the inhabitants of Jinchuan are very concerned about the health risks caused by air pollution.

5 Summary and conclusions

The main purpose of this paper was to demonstrate the importance of sociopsychological factors, particularly knowledge and perception, in averting behavior modeling. We observed that ignorance of such variables leads to loss of information and biased estimators. A second objective was to show that Structural Equation Modelling with latent variables (SEM), is an appropriate way to estimate models with sociopsychological variables (as well as other theoretical constructs or latent variables (bias towards zero) and multicollinearity. A third objective was to estimate the willingness to pay (WTP) for the reduction of air pollution in a heavily polluted mining area (Jinchuan) with relatively low average household income in China.

Based on a cross-sectional data set of 759 households in the Jinchuan mining area, we measured and analyzed environmental knowledge of pollution and perception of health risk correlated with air pollution as well as their impacts on averting behavior using a SEM. Based on the measurement model, we identified two related, though different, dimensions of averting behavior and perception. For averting behavior, the two dimensions were (a) expenditures on air purifying filters and plants, medicine, and curative food (Expenditure), and (b) reduction of outdoor activities (Reduction). For risk perception, the dimensions were intensity of exposure (Exposure) and hazardousness of the pollutants (Hazardousness), respectively.

We found that Exposure positively and significantly induced Reduction in outdoor activities but did not impact Expenditure. The latter strongly responded to Hazardousness. Environmental knowledge impacted both types of perception, but there was no reverse effect. Socioeconomic status, Age, Proximity to the pollution source (PPS), and Work environment (WE) were also found to positively and significantly influence both types of perception. The impact of Family size on Hazardousness was significant and negative. Finally, we found that Environmental knowledge was significantly influenced by Age, Socioeconomic Status, and Work environment.

The main outcome of the analysis is that higher Perceived risk induces people to take action to mitigate negative health effects. The average household WTP for improved air quality as derived from averting behavior (in terms of both Expenditure and Reduction) amounts to 2.95% of the average annual net household income. It follows that air quality improving investments by the mining company or public authorities would substantially decrease the costs of averting health risk. However, because such investments can only be implemented in the medium or long run, short-run policy handles, such as daily disclosure of air quality, would be appropriate. Such policy handles would assist residents to take the right kind and level of risk-reducing actions. Information on local air quality conditions can be made available by social media, tv or radio, possibly in combination with the weather forecast. Suggestions about protective measures, for example, spending more time indoors, can also be made.

This study requires extension in several ways. First, the latent variables Averting behavior, Perceived Risk, and Environmental knowledge need further conceptualization and defining. In this paper, we identified two different dimensions of the first two concepts. It is important to investigate whether there are additional dimensions. Second, the set of test items needs further investigation, revision and expansion. Finally, this paper relates to a specific mining area in China. It is important to understand the universality of the concepts analyzed in this study and their applicability in other geographical settings, notably in developing and newly industrialized countries.

Appendix 1: The estimated initial model¹¹

See Tables 5 and 6.

¹¹ The goodness-of-fit indices indicate that the Initial Model also has satisfactory fit as they all meet their cut off values (in brackets): (χ 2/DF=2.41 (<3), Goodness-of-fit index=0.98 (>0.90), Adjusted goodness-of-fit index=0.97 (>0.90), Standardized root mean square residual=0.029(<0.08), Root mean square error of approximation=0.43 (<0.05)).

Latent variables	Indicators	Coefficient	Standard errors	R^2
Endogenous variables				
Averting behavior (AVB)	AVB1	0.39	0.12	0.16
	AVB2	0.28	0.09	0.08
	AVB3	0.11	0.04	0.01
Perceived health risk (PHR)	PHR1	0.15	0.03	0.02
	PHR2	0.60	0.03	0.36
	PHR3	0.52	0.03	0.28
	PHR4	0.62	0.03	0.38
	PHR5	0.55	0.03	0.3
Environmental knowledge (EK)	EK1	0.51	0.04	0.26
	EK2	0.46	0.03	0.22
	EK3	0.39	0.03	0.15
	EK4	0.48	0.07	0.23
	EK5	0.56	0.04	0.31
	EK5	0.47	0.03	0.22
	EK7	0.31	0.03	0.10
	EK8	0.44	0.04	0.19
Exogenous variables				
Socioeconomic status (SES)	Education	0.47	0.07	0.25
	Income	0.46	0.06	0.20

Table 5 Initial measurement models

Table 6 Initial structural equation model

Variables	AVB	PHR	EK
Averting behaviour (AVB)			
Perceived health risk (PHR)	0.19*		0.20
	(0.10)		(0.22)
Environmental knowledge (EK)		0.54 **	
		(0.30)	
Socioeconomic status (SES)	0.62**	0.16 **	0.30**
	(0.30)	(0.10)	(0.08)
Age (AGE)	0.02		0.07
	(0.05)		(0.03)
Family size (FS)	- 0.07	- 0.08***	
	(0.06)	(0.03)	
Family health experience (FHE)	0.10	0.06**	
	(0.07)	(0.03)	
Medium air pollution (MAP)	- 0.04	0.06	
	(0.08)	(0.08)	

Air pollution and perception-based averting behaviour in...

Table 6 continued

Variables	AVB	PHR	EK
Serious air pollution (SAP)	- 0.03	0.08*	
	(0.08)	(0.08)	
JMC employment not miner or smelter worker (NMS)			0.08
			(0.05)
Miners and smelter workers of JMC (MS)			0.15
			(0.05)
R ²	0.51	0.37	0.18

Standard errors in parenthesis. Significance level: *, **and ***:10%, 5% and 1%, respectively

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Declarations

Conflict of interest The authors declare no conflict of interest.

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