

Article

Environmental Inequality: Change in Labor Allocation During PM_{2.5} Exposure in the Northern Part of Thailand

Mattana Wongsirikajorn

Faculty of Economics, Chiang Mai University, Chiang Mai 50200, Thailand; mattana.w@cmu.ac.th

Abstract

Air pollution from fine particulate matter (PM_{2.5}) is a recurring crisis in Northern Thailand, largely driven by seasonal biomass burning. This study investigates how socioeconomic and individual characteristics shape labor allocation during high-exposure periods. Using survey data from 400 individuals across eight provinces in April–May 2024, we applied a logit model to estimate the probability of reducing work hours. Results show heterogeneous and non-linear patterns of avoidance. The probability of work reduction rose across higher income strata but peaked in the third stratum before declining in the fourth, reflecting the trade-off between avoidance and the opportunity cost of foregone earnings. Education exhibited a strong awareness effect, with each additional year increasing avoidance behavior. Outdoor workers and individuals with respiratory conditions were most likely to reduce work, indicating rational prioritization under greater exposure risks. Together, these findings demonstrate environmental inequality: lower-income and less-educated groups remain disproportionately exposed due to limited coping capacity. The regional context of Northern Thailand further amplifies these vulnerabilities. Policy interventions should prioritize protective measures for vulnerable groups while promoting long-term alternatives to biomass burning. By highlighting nuanced behavioral responses, this study extends evidence on environmental inequality in developing-country contexts.



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Keywords: air pollution; labor allocation; environmental inequality; PM_{2.5}

1. Introduction

Air pollution constitutes a critical environmental problem in developing countries [1]. This phenomenon has arisen from unbalanced economic development, which concurrently generates a negative feedback loop that exacerbates [2,3]. The primary source of air pollution in developing countries, particularly in rural areas, stems from the combustion of organic substances [4,5]. Particulate matter (PM) pollution has emerged as an inevitable byproduct of agricultural activities, notably in Asian nations.

Studies have indicated that PM_{2.5} contributes to economic loss [6–8]. In the short term, it reduces tourism and outdoor economic activities as individuals engage in avoidance behavior toward air pollution [9,10]. However, for workers who are unable or unwilling to reduce their working hours, PM_{2.5} may also diminish their labor productivity through deterioration in health. Therefore, over a longer period of time, the accumulation of PM_{2.5} will adversely affect the health outcomes of workers, resulting in decreased aggregate labor productivity and the growth of the economy [11].

This study seeks to examine whether socioeconomic status influences individuals' labor allocation decisions during periods of high PM_{2.5} exposure in Northern Thailand.

Our investigation revealed disparities in responses, manifested through alterations in labor allocation to air pollution exposure based on socioeconomic status. We hypothesize that individuals of lower socioeconomic status are less likely to reduce their working hours during periods of elevated air pollution. Specifically, we postulate that workers with lower income and education levels exhibit a decreased propensity to diminish their working hours during air pollution exposure periods, thus demonstrating environmental inequality stemming from socioeconomic factors. Explicitly, we formulate the following hypotheses:

H1. *Individuals with higher incomes are more likely to reduce their working hours during PM2.5 exposure periods than those with lower incomes.*

H2. *Individuals with higher educational attainment are more likely to reduce their working hours during PM2.5 exposure periods than those with lower educational attainment.*

H3. *Individuals working outdoors and those with respiratory health issues are more likely to reduce their working hours during PM2.5 exposure periods than individuals without these characteristics.*

Utilizing an individual survey from eight provinces in the upper northern region of Thailand during the dry season, we employed a logit model to estimate the probability of reducing work time during the PM2.5 exposure period based on socioeconomic status. The estimated outcome is expected to elucidate the differences in the probability of change in labor allocation due to variations in income strata and education level, thereby revealing the environmental inequality associated with pollution exposure.

The estimated outcomes aimed at identifying environmental inequality for vulnerable groups. Typically, individuals in lower-income brackets possess fewer resources to cope with a degraded [12–14]. Moreover, low-income households are more likely to reside in areas that are at high risk of natural disasters, as affluent households tend to avoid such locations. The degraded environment would further generate a negative impact on the livelihood of low-income households, reinforcing their disadvantaged status [15,16]. For instance, when lower-income households are unable to avoid exposure to air pollution, prolonged exposure can severely affect health [17]. When health deteriorates, labor productivity also declines, followed by a decrease in income, further exacerbating the economic situation of these households. Therefore, this study aims to demonstrate the mechanism of PM2.5 air pollution in individuals belonging to various income strata.

Our study contributes to the literature in three ways. First, we present empirical evidence of environmental inequality in a Southeast Asian country. Second, we examine the seasonal exposure to PM2.5 air pollution. Third, we investigate the effect of socioeconomic factors at the individual level, including the type of workplace and health outcomes related to the respiratory system. These aspects and the context of environmental inequality remain underexplored in existing literature. We anticipate that the empirical evidence from this study will generate interest from the government and increase public awareness of unequal pollution exposure in society. This awareness may lead to the provision of support for vulnerable households during periods of pollution exposure. The remainder of this paper is organized as follows: Literature Review, Theoretical Framework, Methodology, Results, Discussion, and Conclusions.

2. Literature Review

Economic loss at the individual level may not be equally distributed due to disparities in socioeconomic status, potentially resulting in environmental inequality. Environmental inequality has been extensively studied in Western nations for several decades [18]. The primary focus has been directed toward environmental justice concerning the unequal

distribution of toxic treatment facilities among households with various characteristics, particularly race [19–22]. Subsequent studies in developed countries have shifted attention to examining the relationship between exposure to air pollution, such as particulate matter (PM), sulfur dioxide, ozone, nitrogen dioxide, and socioeconomic status [23–26]. These studies demonstrate that households with varying levels of socioeconomic status experience differential exposure to air pollution. Furthermore, exposure to air pollution has a detrimental effect that could potentially lead to a decline in socioeconomic status through impaired human capital. For instance, Currie et al. [27] found that air pollution resulted in school absences in Texas.

The number of studies addressing environmental inequality in developing countries is significantly lower than that in developed countries, despite the considerable level of environmental degradation. A limited number of studies conducted in China have examined the heterogeneity in the effects of pollution exposure on individuals with different socioeconomic statuses [28,29]. There is a notable paucity of research on developing countries, particularly in Southeast Asia. Figure 1 illustrates the annual mean PM_{2.5} concentrations in Southeast Asia by country. Thailand was ranked fourth in 2019. However, when the most PM_{2.5}-polluted cities were ranked, 7 out of the 15 top cities were in Thailand (Table 1). Among these seven cities, six were located in the upper northern part of Thailand [30]. Therefore, this study elucidates the capacity of individuals with various socioeconomic statuses to cope with degraded environments, focusing on the northern part of Thailand. Despite the increasing international and transboundary issues of air pollution among Southeast Asian countries, research, cooperation, and policy are infrequently addressed. It is imperative to emphasize the challenges faced by individuals of comparatively lower socioeconomic status in sustaining their livelihoods during periods of elevated PM_{2.5} levels.

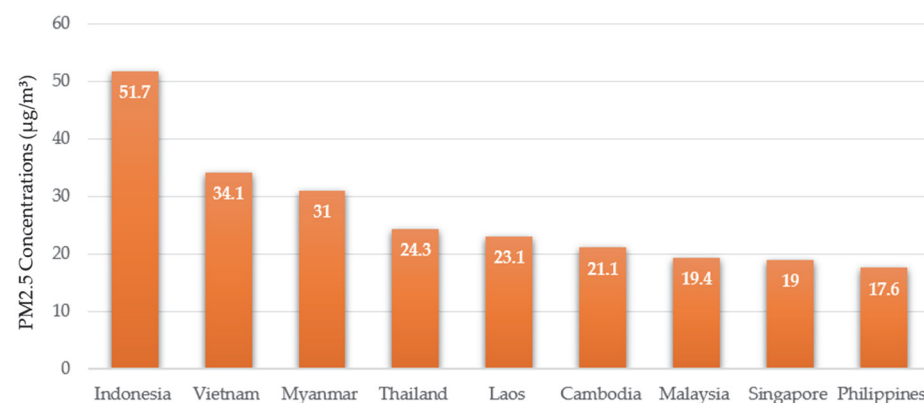


Figure 1. Southeast Asia countries' ranking by their PM_{2.5} annual means (µg/m³). Source: adapted from 2019 World Air Quality Report [30].

The literature on environmental inequality is rooted in the environmental justice movement. The concept of environmental justice emerged as a subject of academic discourse in the United States during the 1980s, when researchers observed that certain segments of the population were disproportionately exposed to harmful pollutants due to specific characteristics such as race [31,32]. Anderton et al. [33] demonstrated a positive correlation between the number of disposal facilities and the proportion of Hispanic residents. Similarly, African Americans were found to be more likely to reside in cities and urban areas with higher levels of pollution [17]. In Florida, African American families were observed to live in closer proximity to sources of industrial toxic releases [14]. Furthermore, toxic air substances were found to be released in greater quantities in locations with higher concentrations of African American communities [34].

Table 1. Most polluted regional cities ranked by level of PM_{2.5} ($\mu\text{g}/\text{m}^3$).

Rank	City	Country	2019 AVG
1	South Tangerang	Indonesia	81.3
2	Bekasi	Indonesia	62.6
3	Pekanbaru	Indonesia	52.8
4	Pontianak	Indonesia	49.7
5	Jakarta	Indonesia	49.4
6	Hanoi	Vietnam	46.9
7	Talawi	Indonesia	42.7
8	Nakhon Ratchasima	Thailand	42.2
9	Saraphi	Thailand	41.3
10	Surabaya	Indonesia	40.6
11	Pai	Thailand	38.9
12	Hang Dong	Thailand	38.0
13	Chinag Rai	Thailand	37.0
14	Mae Rim	Thailand	36.9
15	Mueang Lamphun	Thailand	36.9

Source: adapted from 2019 World Air Quality Report [30].

Environmental inequality, an extension of environmental justice, which primarily focuses on disproportionate exposure to pollution due to racial characteristics, encompasses broader factors, including economic and other social status indicators such as income, assets, education, and ethnicity. Empirical evidence suggests that low-income households are more susceptible to exposure to toxic environments compared to their higher-income counterparts. Related studies can be categorized into two groups based on the types of pollution examined: toxic waste and air pollution. For toxic waste, the central research question aims to determine whether the distance between residential locations and toxic waste disposal or treatment facilities increases proportionally with household income [13,18,35,36]. The majority of these studies utilized panel-structured data from censuses to investigate the relationship between socioeconomic factors and environment-related variables, such as distances from residential areas to hazardous waste facilities.

The literature on environmental inequality also encompasses negative outcomes in economic activity and labor productivity caused by pollution, particularly air pollution. Air pollution diminishes economic efficiency by compromising the factors that constitute human capital, such as health and educational attainment. Research has demonstrated that air pollution has a detrimental impact on academic performance among students of lower socioeconomic status [37]. The reduced academic performance is attributed to two mechanisms. First, air pollution significantly increases school absences [38]. Second, it impairs mental and physical health, which subsequently decreases learning capacity [39]. Air pollution also discourages higher education attainment, which, in the long term, has resulted in the deterioration of the labor market [11]. Furthermore, labor productivity has been observed to decline with an increase in the level of air pollution. Evidence has indicated that polluted air containing high levels of substances, such as ozone and PM_{2.5}, is negatively correlated with levels of productivity in both outdoor and indoor labor [40,41].

Furthermore, air pollution was found to affect labor participation through alterations in time allocation patterns. Air pollution decreases the duration of outdoor activities, which are predominantly employment-related. Specifically, evidence indicates that reductions in

labor participation and working hours are significantly influenced by air pollution [42–44]. The estimated outcomes demonstrated heterogeneity among the samples. This variation was attributed to socioeconomic factors such as age, gender, income, consumption expenditure, and education level [9,43,45]. Focusing on PM_{2.5}, a study found that an increase of 1 $\mu\text{g}/\text{m}^3$ in the concentration of PM_{2.5} decreased work time by 14 min per week and exhibited greater sensitivity among individuals with health problems [46]. A reduction in working hours ultimately results in a decrease in earnings, which is considered a direct economic loss [47,48].

Despite evidence indicating a disproportionate exposure to polluted environments based on socioeconomic status, several studies have not detected a significant relationship establishing environmental inequalities when hazardous waste facilities were not located in closer proximity to communities with specific characteristics, such as ethnic minorities, race, or wealth [33,49,50].

Nevertheless, a key gap in the literature concerns the extent to which socioeconomic inequality shapes behavioral responses to pollution, particularly in developing countries. While studies in Western contexts have emphasized racial and ethnic disparities in exposure, much less is known about how income, education, and health conditions influence avoidance behavior during acute pollution episodes. Existing evidence from China has begun to address these issues, but Southeast Asia remains understudied despite facing recurrent and severe PM_{2.5} crises. Recent studies in the region confirm both the severity and socioeconomic salience of these episodes. For instance, research from Singapore demonstrates that transboundary haze significantly reduces service-sector performance and consumer satisfaction [51], while evidence from Indonesia highlights the substantial health burden of peatland and vegetation fires [52]. In Vietnam, province- and city-level analyses reveal short-term morbidity risks and economic gains from PM_{2.5} reductions [53,54], and studies in Thailand emphasize biomass-burning-driven haze in the North [55], elevated health risks among children [56], and disproportionate impacts on informal and outdoor workers in Bangkok [57]. Regionally, socioeconomic determinants of PM_{2.5} exposure have also been documented through spatial panel analyses in Thailand [58]. Together, these findings underscore that Southeast Asia not only faces recurrent pollution shocks but also exhibits pronounced inequalities in exposure and coping capacity.

Moreover, the majority of prior research has focused on static exposure or proximity to pollution sources, with limited attention to the dynamic dimension of how individuals adjust their labor allocation as a coping strategy. Addressing this gap, the present study examines avoidance behavior in Northern Thailand, thereby extending the literature to a context where seasonal air pollution episodes are both socially widespread and economically disruptive.

In light of evidence both supporting and opposing the existence of environmental inequality, our research contributes empirical evidence to this inconclusive debate. Specifically, the following contributions are made to the literature. First, we focus on seasonal air pollution, which exhibits characteristics distinct from those of immobile waste facilities in previous literature. Second, this study is conducted in a developing country, a context that has been infrequently examined in terms of environmental inequality. Third, contextualized main control variables, such as the type of workplace, individual respiratory health outcomes, and income consistency, are incorporated into the estimation.

3. Theoretical Framework

This study employs the theory of time allocation [59]. According to this theoretical framework, households are conceptualized as production units within an economic system. To achieve optimal outcomes, households maximize their utilities, subject to time

constraints. Time can be considered an extractive resource, as the allocation of time to one activity necessarily reduces the time available for others. Consequently, households must distribute time among various activities and select a combination that yields maximum utility. The value of time for households in the labor market is reflected in wages. By allocating more time to work, households can increase their wages, which are subsequently used to purchase goods and services that enhance utility levels. Conversely, opting to work more simultaneously diminishes the opportunity for leisure activities, which also contributes to increased utility. Assuming rational economic agents, households will primarily allocate time between work and leisure in a manner that maximizes utility. Therefore, a change in the pattern of time allocation is presumed to result in increased household utility.

We posited that individuals alter their time allocation during periods of exposure to PM2.5. This hypothesis is based on the premise that exposure to PM2.5 diminishes their utility through the deterioration of health. Consequently, to maintain the same level of utility as before exposure to PM2.5, individuals are likely to reduce their work hours. However, this reduction in working hours results in a decrease in income, which subsequently leads to a decline in utility. We postulate that the change in labor allocation will be characterized by a degree of heterogeneity, influenced by factors such as income, workplace, health status, and demographic variables. Specifically, we hypothesize that individuals with lower income are less likely to reduce their work time, as the unpaid absence from work would constitute a larger proportion of their income compared to individuals who typically earn higher income.

The presence of outdoor workplaces, respiratory health issues, and income stability is anticipated to increase the probability of worktime reduction during exposure to PM2.5. Moreover, individuals with higher educational attainment are more likely to engage in avoidance behaviors due to their enhanced awareness of PM2.5's detrimental health effects. These factors were considered as the primary controlled variables. The additional control variables comprise explanatory demographic factors, including age, gender, family size, marital status, and household head status.

According to Becker [59], individuals derive utility from consumption. However, consumption is generally facilitated by income, which is obtained through labor participation in the economic system. Consequently, rational economic agents allocate their time between work and leisure activities to maximize their utility. The households aim to maximize the following utility function:

$$U(Z_1, \dots, Z_m), \quad (1)$$

With the following constraints:

$$Z_i = f_i(X_i, T_i), \quad i = 1, \dots, m. \quad (2)$$

$$\sum_{i=1}^m \pi_i Z_i = \omega T + V \quad (3)$$

Z_i is a commodity on which households' utility depends (1). To acquire Z_i , households must combine a vector of goods, X_i , and time T_i (2). π_i is the price of commodity i . The budget constraint of households depends on full income, which is the combination of the price of time ω multiplied by the amount of time used T for all activities, where $T = \sum T_i$, and V , the unearned income or the income received without time spent (3).

In our study, we consider exposure to PM2.5 as a factor that diminishes the quality of X_i , which subsequently reduces individuals' utility. For instance, X_1 could be conceptualized as a picnic meal on a typical holiday. PM2.5 decreases the enjoyment of outdoor picnicking as individuals may experience increased difficulty in breathing, *ceteris paribus*, compared to conditions without PM2.5. Consequently, Z_i decreases during the PM2.5 exposure period. The implications of utility reduction can be examined in two ways.

Firstly, individuals will require greater quantities of other goods, such as X_2 which could be interpreted as a meal in a reputable restaurant, to compensate for the reduced quality of X_1 . Thus, to acquire more of X_2 , the household must allocate more time to work to obtain higher income levels to afford more of X_2 . However, increasing work time may lead to greater exposure to PM2.5 and create a feedback loop that further decreases utility. Therefore, the second approach involves individuals minimizing the cost of damage caused by PM2.5 by allocating less time to work, rather than attempting to maintain maximized utility. Nevertheless, we hypothesize that these two behavioral directions are contingent upon socioeconomic status. Individuals in high-income strata are more likely to reduce their work time because the income loss due to work absence during the PM2.5 exposure period will constitute a smaller proportion of their total income compared to those in lower income strata. For individuals in low-income strata, work absence will result in income loss with a relatively higher opportunity cost in acquiring other goods, X_i . PM2.5 is considered a public bad, characterized by non-rivalry and non-exclusivity for all members of society. However, the impact of PM2.5 is heterogeneous across individuals, depending on their capacity to engage in avoidance behavior. When this capacity varies according to socioeconomic status, there is an increase in environmental inequalities.

4. Materials and Methods

4.1. Data and Study Sites

A survey was conducted from April to May 2024, during the dry season, in eight provinces in the upper-northern region of Thailand: Chiang Mai, Chiang Rai, Lampang, Lamphun, Mae Hong Son, Nan, Phayao, and Phrae (Figure 2). The survey period coincides with the annual peak of the haze crisis in Northern Thailand. During this period, air quality index (AQI) levels reached at least the red zone (“unhealthy”) for extended durations across the region. We therefore treat the survey period as representing the PM2.5 exposure period of concern in this study. Although PM2.5 is also present in other months, concentrations outside this season are typically lower and do not reach crisis levels.

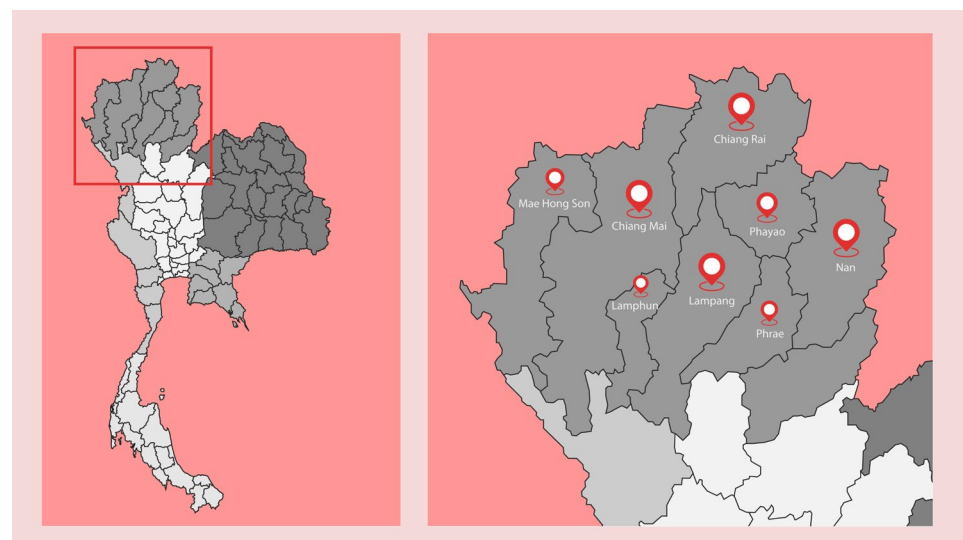


Figure 2. Map of the eight survey provinces in Northern Thailand (Chiang Mai, Chiang Rai, Lampang, Lamphun, Mae Hong Son, Nan, Phayao, and Phrae). Each province contributed 50 respondents to the survey, resulting in a total sample of 400 individuals.

It should be noted that this study focuses on PM2.5 rather than other pollutants such as PM10 or SO₂. The rationale is that during the dry season haze crisis in Northern Thailand, PM2.5 is the dominant pollutant driving AQI levels into the red zone. Reports from the

Pollution Control Department and international monitoring agencies consistently identify PM_{2.5} as the critical pollutant during this period, whereas concentrations of other pollutants are relatively lower and do not reach crisis levels. Therefore, while other pollutants may be present, the health and behavioral impacts observed during the survey period can be reasonably attributed to PM_{2.5} exposure.

The occurrence of PM_{2.5} pollution in Northern Thailand is strongly associated with biomass burning, including crop residue burning to prepare land for cultivation in the coming rainy season and forest fires during the dry season. In such conditions, individuals adopt various avoidance strategies, such as reducing outdoor work, staying indoors, using air purifiers, and wearing protective masks.

A total of 400 samples were collected. Data were collected through face-to-face interviews conducted in the field. To ensure representativeness, we sampled 50 individuals from each of the eight provinces, resulting in a total of 400 respondents. The survey comprised questions pertaining to socioeconomic status, labor allocation, working conditions, health outcomes, social security, and coping strategies during the dusty season.

Descriptive statistics are presented in Table 2. The ages of respondents ranged from 20 to 76 years. The proportion of female respondents was 51 percent. The average household size was 3.43 members. Twenty-four percent of the respondents reported working outdoors. The average monthly income per household member was approximately 8113 baht (USD 241.49).

Table 2. Descriptive statistics.

Variable	Mean	S.D.	Min	Max	N
Age	48.05	13.13	20	76	400
Female (1 = Yes)	0.51	0.50	0	1	400
Household size	3.43	1.39	0	10	400
Monthly income per capita	8113.64	9596.88	0	100,000	399
Years of education	10.32	4.88	0	19	400
Reduce work time (CLA) (1 = Yes)	0.068	0.251	0	1	400
Working outdoors (1 = Yes)	0.24	0.42	0	1	400
Having respiratory health issue (1 = Yes)	0.063	0.242	0	1	400
Income consistency (1 = Yes)	0.275	0.45	0	1	400
Head of the household (1 = Yes)	0.5425	0.499	0	1	400
Living in municipality (1 = Yes)	0.5	0.501	0	1	400

Note: 1. Monthly income per capita is in Baht 2. For Reduce work time, we asked the individuals whether they reduced working hours during the survey period or not. 3. The mean of a dummy variable represents a proportion. 4. The number of observations for “Monthly income per capita” is 399 because one response was excluded due to missing value, which would have unduly influenced the descriptive statistics.

4.2. Estimated Model

To examine the probability that an individual reduces working time during periods of high PM_{2.5} exposure, we employ a binary logit model. The logit model estimates the log-odds of the dependent variable as a linear combination of explanatory variables, Equation (4). Unlike a linear probability model, the logit specification constrains the predicted probabilities to fall between 0 and 1, making it more appropriate for binary outcomes. Equation (5) thus specifies the log-odds of reducing work time as a function of income strata, education, workplace type, health condition, and demographic factors. The marginal effects are reported to facilitate interpretation in terms of probabilities.

$$\text{logit}(P(Y_i = 1)) = \ln\left(\frac{P(Y_i = 1)}{1 - P(Y_i = 1)}\right) \quad (4)$$

$$\begin{aligned}
 CLA_i = \alpha_0 + \beta_1 2ndincome_strat_i + \beta_2 3rdincome_strat_i + \\
 \beta_3 4thincome_strat_i + \beta_4 Education_i + \beta_5 WorkOutdoor_i + \\
 \beta_6 RespHealth_i + \beta_7 Age_i + \beta_8 Age_i^2 + \beta_9 Female_i + \\
 \beta_{10} HHhead_i + \beta_{11} IncomeCon_i + \beta_{12} Municipality_i + \epsilon_i,
 \end{aligned} \quad (5)$$

where

- $P(Y_i = 1)$ is the probability that individual i reduces working time.
- CLA_i is a dummy variable indicating the extensive margin of change in labor allocation, equal to 1 if individual i reduces working time during the survey period and 0 otherwise.
- $2ndincome_strat_i$, $3rdincome_strat_i$, and $4thincome_strat_i$ are dummy variables equal to 1 if individual i is in the second income strata, third income strata, and fourth income strata, respectively, and 0 otherwise.
- $Education_i$ is the year of education of individual i .
- $WorkOutdoor_i$ is a dummy variable equal to 1 if individual i works outdoors, and 0 otherwise.
- $RespHealth_i$ is a dummy variable equal to 1 if individual i has health issues related to the respiratory system, and 0 otherwise.
- Age_i is the age in years of individual i .
- $Female_i$ is a dummy variable equal to 1 if individual i is female, and 0 otherwise.
- $HHhead_i$ is a dummy variable equal to 1 if individual i is the head of the household and 0 otherwise.
- $IncomeCon_i$ is a dummy variable equal to 1 if the income of individual i is consistent and 0 otherwise.
- $Municipality_i$ is a dummy variable equal to 1 if individual i resides in the municipality, and 0 otherwise.

Our empirical specification builds on Becker's time allocation framework mentioned earlier, which conceptualizes household decisions as the allocation of time across competing activities under resource constraints [59]. Building on this theoretical foundation, several recent studies have employed binary choice models to analyze labor and time allocation decisions. For instance, Bang et al. [60] develop and estimate a discrete-choice model of access and exposure to local news media in U.S. markets, relying on logit-type estimations to explain individual time-use patterns. In the context of environmental shocks, Takasaki et al. [61] apply a two-step probit model to examine households' labor allocation responses to flood-induced crop losses in the Amazon. These precedents support our application of a logit model to study the probability of reducing work during PM2.5 exposure episodes in Northern Thailand.

5. Results

The probability of reducing work increases with higher-income strata, demonstrating inequality in avoidance behavior among different income levels (Table 3). Using the lowest income stratum as the baseline, the probability of reducing work during the PM2.5 exposure period significantly increases by 7 percent for the second income stratum, 8.6 percent for the third income stratum, and 7.1 percent for the fourth income stratum. Furthermore, having an outdoor workplace increases the probability of reducing work time by 9.5 percent at a significance level of 0.01. Individuals with health issues related to the respiratory system exhibit an 11 percent increase in the probability of reducing work time, which is statistically significant at the 0.01 level. Years of education also positively correlate with the probability of reducing work time. Each additional year of education increases the probability of reducing work by 0.7 percent, which is statistically significant at the

0.05 level. This outcome further indicates that individuals with higher levels of education are more likely to engage in avoidance behavior, thereby protecting themselves from exposure to air pollution.

Table 3. Probability of reducing work during PM2.5 period.

Variable	Reducing Work	Marginal Effect
Being in 2nd income strata (1 = Yes)	2.384 ** (1.159)	0.070
Being in 3rd income strata (1 = Yes)	2.628 ** −1.195	0.086
Being in 4th income strata (1 = Yes)	2.405 ** −1.172	0.071
Years of education	0.133 ** (0.061)	0.007
Outdoor workplace (1 = Yes)	1.759 *** (0.521)	0.095
Have respiratory health issue (1 = Yes)	2.038 *** (0.682)	0.110
Income consistency (1 = Yes)	−0.880 (0.678)	
Age	−0.156 −0.105	
Age ²	0.002 (0.001)	
Female (1 = Yes)	0.526 (0.525)	
Being head of household (1 = Yes)	0.366 −0.497	
Living in municipality (1 = Yes)	0.525 (0.473)	
Constant	−4.256 −2.697	
Observations	399	
Log likelihood	−78.033	
Likelihood Ratio χ^2 (12)	41.49	
Pseudo R ²	0.21	

Notes: Standard errors are shown in parentheses; *** $p < 0.01$, ** $p < 0.05$.

To ensure the robustness of the findings, additional analyses were conducted. First, the model was re-estimated using a probit specification. Second, a restricted logit specification including only statistically significant predictors was tested. As reported in Appendix A Table A1, both robustness checks yield qualitatively consistent results with the baseline logit estimates, reinforcing the stability of the main conclusions. Furthermore, multicollinearity diagnostics based on Variance Inflation Factors (VIFs) indicate that no explanatory variable exhibits problematic levels of collinearity.

6. Discussion

The estimated coefficients of income strata are all positive and statistically significant at the 0.05 level. This result indicates that, compared to the bottom stratum, being in the higher strata increases the probability of work time reduction. The unequal likelihood of this avoidance behavior during exposure to PM2.5 implies environmental inequality. The lowest-income group exhibited the lowest probability of engaging in avoidance behavior when the level of exposure to hazardous air pollution correlated with socioeconomic status. This outcome aligns with the findings of Ash & Fetter [17], Kruize et al. [62], Perline

et al. [63], and Verbeek [64], which suggest that the low-income segment of the population is likely to be exposed to pollution. However, the probability of avoidance behavior did not increase proportionally. The probability of performing avoidance behavior decreased in the highest or fourth income stratum compared to the third income stratum. This result can be attributed to the dominant income effect. Individuals in the highest income stratum face the highest opportunity cost of income loss, thus demonstrating a decreased probability of reducing work time compared to those in the third income stratum.

Education is another socioeconomic factor that significantly influences environmental inequalities. According to the estimated outcome, an additional year of education is associated with a higher probability of avoidance behavior. Consequently, individuals with different levels of education choose to cope with PM_{2.5} differently. Individuals with higher levels of education are more likely to reduce their exposure to PM_{2.5} by reducing work time. This finding is consistent with Currie et al. [21], who observed that lower education levels correlate with higher chances of being exposed to air pollution. Other statistically significant control variables include having outdoor workplaces and health issues related to the respiratory system, both significant at the 0.01 level. The highest significance levels and probabilities indicate the rationality of the factors prioritized when exposed to PM_{2.5}. For individuals with respiratory health issues, exposure to PM_{2.5}, compared to those without exposure, will generate a more severe negative outcome. Thus, the probability of worktime reduction due to respiratory health issues is high. Similarly, for outdoor workplaces, the same rationale applies: having an outdoor workplace increases the severity of exposure to PM_{2.5}. Consequently, individuals who typically work outdoors have a higher probability of worktime reduction than those who do not work outdoors.

In line with the hypotheses, the results confirm that income and education significantly increase the probability of reducing work time during periods of high PM_{2.5} exposure, although the effect of income is not strictly proportional across strata due to higher opportunity costs in the top income group. Education consistently enhances avoidance behavior, suggesting a strong awareness effect. Moreover, individuals with outdoor workplaces and respiratory health issues also exhibit a higher likelihood of reducing their working hours, consistent with expectations. Together, these findings verify our hypotheses and provide clear evidence that socioeconomic status and related individual characteristics shape avoidance behavior during pollution episodes, thereby reinforcing patterns of environmental inequality.

One limitation of the present analysis is that the dependent variable (CLA) is measured in binary form, indicating whether respondents reduced their working time during the PM_{2.5} period. This coarse measure does not capture the intensity, frequency, or duration of work reductions, which may conceal heterogeneity in avoidance behaviors across individuals. Future research employing time-use diaries or longitudinal tracking would provide a more nuanced understanding of behavioral responses. Nevertheless, the results highlight that socioeconomic status does not simply reflect financial capability but fundamentally structures individuals' ability to avoid exposure. Higher-income and better-educated groups can more readily shift to indoor work or adopt protective measures, while lower-income and informal workers remain disproportionately exposed due to structural constraints. This pattern reinforces the interpretation of avoidance behavior as an expression of environmental inequality.

7. Conclusions

This study examines environmental inequality by analyzing the relationship between income strata and changes in the extensive margin of labor allocation during periods of PM_{2.5} exposure in the upper northern region of Thailand. The population was divided into

four income strata, and the estimated results indicate that belonging to a higher-income stratum increases the probability of worktime reduction. Although the increases are not proportional, the probabilities in the second to fourth income strata are statistically significantly higher than the first income stratum. The probability of work time reduction is highest in the third income stratum, before decreasing in the fourth income stratum, demonstrating the income effect of having a higher opportunity cost for foregone income. Additionally, the findings reveal that increased years of education correlate with a higher probability of work time reduction. This reflects an awareness effect, whereby education enhances recognition of pollution risks and the capacity to take protective action. Collectively, these results underscore the higher likelihood of exposure to deteriorated environmental conditions among populations of lower socioeconomic status. Moreover, outdoor workers and individuals with respiratory health conditions displayed the highest likelihood of avoidance behavior, indicating rational prioritization under greater exposure risk.

While this study provides new empirical evidence on environmental inequality and avoidance behavior during PM_{2.5} exposure in Northern Thailand, several limitations should be acknowledged. First, the data are based on a cross-sectional survey conducted in a single season, which constrains the ability to infer long-term behavioral patterns or causal effects. Second, self-reported information on labor allocation and health conditions may be subject to recall bias or reporting error. Third, the study is limited to eight provinces in Northern Thailand and may not capture heterogeneity in other regions or countries with different institutional settings.

These limitations point to promising avenues for future research. Longitudinal or panel data would allow examination of how avoidance behaviors evolve across time and repeated pollution episodes. Expanding the analysis to other regions in Southeast Asia could provide comparative insights into transboundary pollution dynamics and socioeconomic disparities. Moreover, integrating objective health data and high-frequency labor market indicators would strengthen the robustness of findings. Finally, investigating the effectiveness of policy interventions aimed at supporting vulnerable groups during pollution episodes would provide actionable evidence for policymakers. At the same time, it should be noted that the present survey, although stratified across eight provinces, was based on a modest sample size and therefore cannot be considered fully representative of Northern Thailand, let alone the entire country. The findings should thus be interpreted as exploratory evidence, with future research requiring larger and nationally representative samples to validate and generalize these results.

Based on these findings, this study advocates for the implementation of appropriate and inclusive policies that focus more on vulnerable groups during periods of air pollution exposure. With less protection during regular periods, vulnerable groups have significantly fewer options for coping strategies during periods of pollution exposure. Without proper intervention, a polluted environment could repeatedly diminish labor capacity and potentially lead individuals to even lower socioeconomic outcomes. Short-term policy responses could include providing protective equipment and temporary income support for outdoor and informal workers during severe haze episodes. Such measures directly address the groups identified in our analysis as most vulnerable—outdoor workers and those with health limitations—who rationally prioritize avoidance when possible but often lack sufficient protection. Medium-term interventions should promote alternatives to biomass burning in agriculture, while long-term measures should focus on strengthening social protection and occupational health frameworks. Taken together, these actions would reduce the unequal burden of PM_{2.5} pollution and mitigate the reproduction of environmental inequality in labor markets.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki. We would like to confirm that our study, titled “Environmental inequality: Change in labor allocation during PM2.5 exposure on the Northern part of Thailand”, involved anonymous survey data collected from adult participants without gathering any personal identifiers, sensitive health information, or any data that could be traced back to individuals. According to the national ethical guidelines in Thailand—The Ethical Guidelines for Research on Human Subjects in Thailand, B.E. 2550, published by the Forum for Ethical Review Committees in Thailand (FERCIT)—research involving anonymous, non-identifiable, and minimal-risk data collection is exempt from requiring IRB or ethics committee approval. Specifically: “If the data are de-identified, not re-identifiable, anonymous data... ethical approval may be waived.” (Chapter 7.2) Additionally, all participants were informed about the purpose of the research and voluntarily participated in the survey without any form of coercion. The study did not involve any physical, psychological, legal, or social risk to participants. We therefore confirm that ethics approval was not required for this research under Thai national regulations, and the study was conducted in accordance with the principles outlined in the Declaration of Helsinki (1975, revised in 2013), as applicable to non-interventional, low-risk social science research.

Informed Consent Statement: Verbal informed consent was obtained from all participants prior to the interviews. Verbal consent was chosen instead of written consent because some subjects were unskilled laborers with limited literacy, which made written consent impractical.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The author declares no conflicts of interest.

Appendix A

Appendix A.1

Table A1 reports the robustness checks of the main results. In addition to the baseline logit specification presented in Table 3, two alternative models were estimated. First, a probit specification was employed as an alternative binary choice model. Second, a restricted logit specification was estimated by retaining only the statistically significant predictors from the baseline model. Across both specifications, the signs and levels of statistical significance of the key explanatory variables—education, outdoor workplace, and respiratory health—remain qualitatively consistent with the baseline logit estimates. These results provide reassurance that the main findings are not sensitive to the choice of binary regression model or the inclusion of non-significant covariates.

Table A1. Probit and Logit estimates of the probability of reducing work during PM2.5 exposure (robustness check).

Variable	Probit		Logit	
	Reducing Work	Marginal Effect	Reducing Work	Marginal Effect
Being in 2nd income strata (1 = Yes)	0.926 ** (0.438)	0.068	2.371 ** (1.136)	0.067
Being in 3rd income strata (1 = Yes)	0.969 ** (0.452)	0.074	2.618 ** (1.162)	0.084
Being in 4th income strata (1 = Yes)	0.879 ** (0.444)	0.062	2.502 ** (1.143)	0.076
Years of education	0.064 ** (0.03)	0.007	0.122 ** (0.055)	0.007
Outdoor workplace (1 = Yes)	0.862 *** (0.266)	0.093	1.821 *** (0.448)	0.102

Table A1. Cont.

Variable	Probit		Logit	
	Reducing Work	Marginal Effect	Reducing Work	Marginal Effect
Have respiratory health issue (1 = Yes)	0.996 *** (0.353)	0.107	1.995 *** (0.631)	0.111
Income consistency (1 = Yes)	−0.359 (0.31)			
Age	−0.068 (0.054)			
Age ²	0.001 (0.001)			
Female (1 = Yes)	0.26 (0.272)			
Being head of household (1 = Yes)	0.208 (0.257)			
Living in municipality (1 = Yes)	0.26 (0.229)			
Constant	−2.158 (1.356)		−7.115 *** (1.353)	
Observations	399		399	
Log likelihood	−79.253		−81.129	
Likelihood Ratio χ^2 (12)	39.05		35.3	
Pseudo R ²	0.198		0.179	

Notes: Standard errors are shown in parentheses; *** $p < 0.01$, ** $p < 0.05$.

Appendix A.2

Variance Inflation Factors (VIFs) were calculated to assess potential multicollinearity among explanatory variables. Although the quadratic specification for age (age and age squared) naturally produces high VIF values, the remaining covariates all exhibit VIFs well below the conventional threshold of 10. The mean VIF is 8.80, suggesting that multicollinearity is not a serious concern for the estimated models.

Table A2. Variance Inflation Factor (VIF) test for multicollinearity.

Variable	VIF	1/VIF
Income strata 2	1.61	0.619
Income strata 3	1.68	0.596
Income strata 4	1.67	0.597
Education (years)	1.36	0.735
Outdoor workplace	1.26	0.795
Respiratory health	1.07	0.938
Age	46.24	0.022
Age ²	45.5	0.022
Female	1.51	0.664
Head of household	1.43	0.698
Income security	1.24	0.809
Municipality	1.08	0.925
Mean VIF = 8.80		

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