Does Fine Particulate Matter Affect Parental Childcare Time?:
The Gendered Effects of Air Pollution

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Abstract

This study examines whether fine particulate matter affects parental childcare time, particularly focusing on the difference between mothers and fathers. Fine particulate matter pollution threatens children's health and can shorten operational hours of childcare centers and educational institutions. Given these conditions, fine particulate matter is likely to increase parental childcare time. Combining the 2019 Korean Time Use Survey with fine particulate matter data, this study employs random effects Tobit models for analysis. The results show no significant relationship between fine particulate matter levels and parental childcare time. However, the impact of fine particulate matter on parental childcare time exhibited gender disparities, with increased fine particulate matter levels correlating with more time mothers spend on primary and simultaneous childcare activities and being with children. Conversely, fathers' caregiving time decreased. These findings highlight that fine particulate matter can worsen existing gender inequality in childcare. This study concludes by discussing implications for policy and methodology and suggesting future research directions.

Keywords: Fine Particulate Matter, Childcare Time, Gendered Effect, Korean Time Use Survey

알기 쉬운 요약

이 연구는 왜 했을까? 초미세먼지는 어린아이의 건강을 위협하고, 심할 경우 어린이집과 유치원, 초등학교의 운영 시간을 단축시킬 수 있다. 따라서 초미세먼지 농도가 높아질수록 부모의 자녀 돌봄 시간이 늘어날 것으로 예상된다. 이 연구는 실제로 초미세먼지 농도가 자녀 돌봄 시간에 영향을 미치는지, 엄마와 아빠에게 똑같은 영향을 미치는지를 알아보았다.

새롭게 밝혀진 내용은? 초미세먼지 농도와 부모의 자녀 돌봄 시간은 관계가 없는 것으로 나타났다. 그러나 초미세먼지 농도가 엄마와 아빠에게 미치는 영향은 달랐다. 초미세먼지 농도가 높아질수록 엄마가 자녀를 직접 돌보는 시간, 자녀와 함께 보내는 시간이 늘어난 반면, 아빠의 자녀 돌봄 시간은 감소하였다.

앞으로 무엇을 해야 하나? 초미세먼지 대응과 감소 정책에 엄마와 아빠 간의 돌봄 불평등 요소가 포함되지 않도록 정책을 신중하게 만들고, 시행하고, 평가해야 한다. 그리고 환경과 사회 영역을 통합하는 데이터 구축이 필요하다.

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Ⅰ. Introduction

It is now customary to check the concentration of fine particulate matter when reviewing the daily weather forecast. Fine particulate matter, known as PM2.5, consists of dust particles smaller than 2.5 micrometers in diameter. PM2.5 has emerged as a critical pollutant under surveillance leading the Korean government to enact the Special Act on the Reduction and Management of Fine Dust in 2019, aimed at combatting air pollution. In Seoul, the number of days with PM2.5 watches and warnings rose from six in 2015 to 17 in 2019, then slightly decreased to 12 in 2021, primarily due to the government's efforts to reduce substances emitting PM2.5 and the implementation of social distancing measures during the COVID-19 pandemic (국립환경과학원, 2022, p.42). However, despite these efforts, Korea's average annual PM2.5 concentration was 20.3 ㎍/㎥ in 2020, double the average of the 36 member countries in the Organisation for Economic Co-operation and Development (OECD) and four times the World Health Organization's guideline (Energy Policy Institute at the University of Chicago, 2022).

PM2.5 mainly arises from the combustion of fuels in factories and vehicles, comprising ionic components like sulfate, nitrate, and ammonia, along with harmful substances such as metal and carbon compounds. PM2.5 particles are so fine that they can penetrate the lungs upon inhalation. The United States Environmental Protection Agency determined in 2019 that PM2.5 has severe health effects, impacting the respiratory, cardiovascular, and nervous systems (U.S. EPA, 2019). Children are particularly susceptible to severe health conditions due to PM2.5 exposure, with an estimated 600,000 child deaths in 2016 attributed to the combined effects of ambient and household PM2.5. Air pollution significantly threatens children's health, accounting for nearly one in 10 deaths in children under five years old (WHO, 2018).

High concentrations of PM2.5 affect not only health but also time allocation. Several economists have shown that PM2.5 air pollution can reduce working hours (서병선, 임형선, 2019; Aragón, Miranda & Oliva, 2017; Fan & Grainger, 2019). Two potential explanations exist: workers may miss work due to illness when PM2.5 levels are high, or they may need to care for sick dependents (Aragón, Miranda & Oliva, 2017, p.308). Studies on air pollution and labor supply have empirically tested the first hypothesis, but the second is generally assumed, suggesting that caregiving responsibilities in households with dependents could decrease working hours (Aragón, Miranda & Oliva, 2017; Kim, Manley & Radoias, 2017; Montt, 2018). Indeed, air pollution significantly reduces working hours for individuals with dependents but less so for those without (Kim, Manley & Radoias, 2017). Furthermore, it is primarily women, often the main caregivers, who tend to reduce their working hours (서미숙, 2015; Aragón, Miranda & Oliva, 2017). In China, where grandparents typically provide childcare, the impact of PM2.5 on labor supply is similar between parents and non-parents (Fan & Grainger, 2019). These findings support the idea that caregiving may decrease labor supply as air pollution levels rise. However, the actual relationship between PM2.5 pollution and childcare time is not well-understood.

This study investigates the impact of PM2.5 pollution on childcare time. PM2.5 is known to adversely affect children's health, and previous research has established a correlation between particulate matter pollution and school absences (Ransom & Pope, 1992; Park, Lee, Ha, Lee, Kim & Hong, 2002). Additionally, the Korean government recommends temporarily closing childcare centers, kindergartens, and elementary schools when PM2.5 concentrations are predicted to exceed specific standards under the Special Act on the Reduction and Management of Fine Dust.[1] Given these conditions, PM2.5 is likely to

1) Local governments can recommend temporary closures when the 24-hour average PM2.5 concentration is predicted to exceed 75 ㎍/㎥ for

increase parental childcare time.

Accurately measuring childcare time is crucial for assessing the economic value of the time parents invest in their children (Folbre, Yoon, Finnoff & Fuligni, 2005, p.388). Most research on childcare time in Korea is based on primary activities (배호중, 2015; 김진욱, 권진, 2017; 허수연, 김한성, 2019; 김유경, 2022). However, this method may not capture all the time parents devote to childcare. Firstly, since most time-use surveys ask respondents about their specific activities, invisible caregiving work might go unrecorded as childcare. For example, when parents care for a sick child due to PM2.5 pollution, they may not be actively engaged in caregiving at all moments. They might have moments of respite during the child's sleep but remain concerned about their child. Not including this invisible caregiving in childcare calculations can underestimate childcare time (윤자영, 2018; Folbre, Yoon, Finnoff & Fuligni, 2005). Secondly, parents often care for their children while also doing other activities. Daily life involves concurrent tasks, such as preparing for work while dressing children. If time use is recorded based only on a primary activity, like getting ready for work, it might miss how childcare is integrated into these routines, underestimating childcare time (권순범, 진미정, 2016, p.28). To address these issues, this study measures childcare time in three ways: as a primary activity, as a simultaneous activity, and in a broader context. By comparing PM2.5 levels with these three forms of childcare, this study aims to illuminate how parents respond to PM2.5 pollution.

Moreover, this study examines whether gender differences exist in the impact of PM2.5 pollution on childcare time. Mothers are generally more involved in childcare than fathers, even in countries with high gender equality (Eriksson & Nermo, 2010, p.345). In Korea, where traditional gender roles persist, mothers often take on the primary caregiving role, even when both parents are employed. Fathers are increasingly engaged in childcare, but their care methods differ from mothers. This study investigates how fathers and mothers spend time with their children and whether their childcare approaches differ with rising air pollution levels.

PM2.5 is more than an environmental concern. Extensive economic literature indicates that PM2.5 reduces labor supply, with gender-specific effects, but social research on this topic is limited. This study helps fill this gap by examining PM2.5's impact on childcare time, focusing on gender differences.

Ⅱ. Literature Review

1. Particulate matter and its effects

Korea established environmental standards for PM2.5 in 2015 and has monitored airborne PM2.5 concentrations since then. The average annual PM2.5 concentration gradually declined from 26 ㎍/㎥ in 2015 to 18 ㎍/㎥ in 2021 (국립환경과학원, 2022, p.27). [Figure 1] illustrates the average regional and monthly PM2.5 concentrations for 2021. PM2.5 levels tend to be higher in the densely populated capital area, especially during the stable atmospheric conditions of winter and spring. Air quality is deemed poor and very poor when the daily average PM2.5 concentration ranges from 36 to 75 ㎍/㎥ and exceeds 76 ㎍/㎥, respectively. In 2021, there were 22 days with poor air quality and one day with very poor air quality nationwide (국립환경과학원, 2022, p.24), meaning that approximately fifty million people were exposed to unhealthy air quality for nearly one month within the year.

PM2.5 is known to adversely affect young children's health. Local governments can recommend temporary closures of childcare centers, kindergartens, and elementary schools when predicted PM2.5 concentrations reach levels necessitating emergency reduction measures. There was

a day or 50 ㎍/㎥ for two consecutive days.

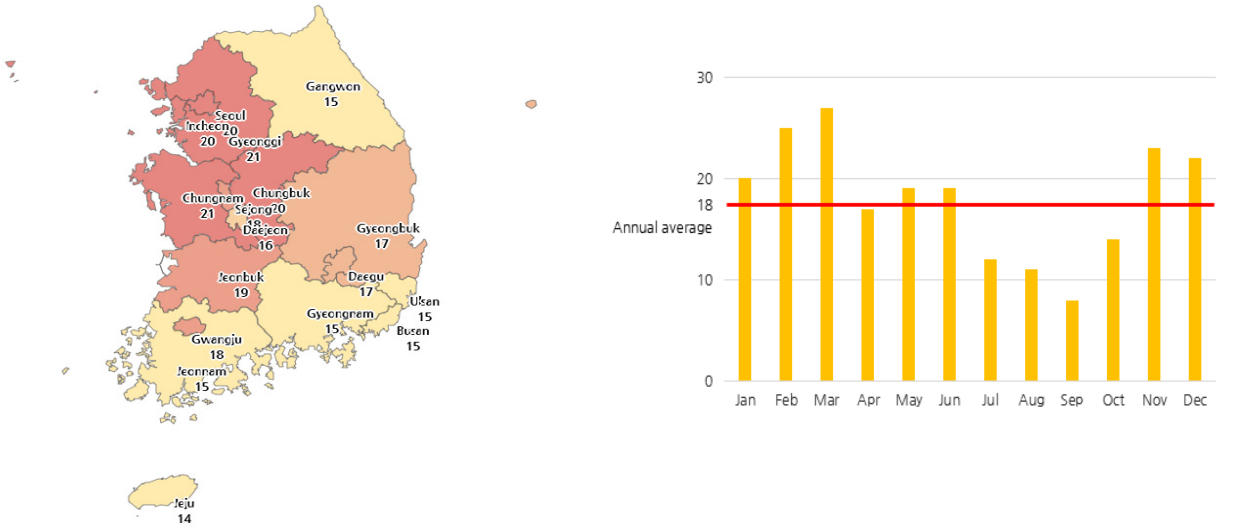
discontent among working mothers when the Korean government announced its emergency reduction plan in 2019. In response, the government stated that closure recommendations would be minimized, even under emergency reduction measures, and alternative childcare services would be provided for dual-earner families (정책브리핑, February 20, 2019). However, considering previous research on the relationships between air pollution and school absenteeism, as well as air pollution and parents' working hours, it is plausible that parents' childcare time increases as PM2.5 pollution levels rise.

Ransom & Pope (1992) assessed the association between elementary school absenteeism and PM10 pollution in two U.S. school districts. They found a significantly positive correlation between absenteeism and PM10 levels, with effects persisting for up to four weeks. Absenteeism responses to PM10 pollution were more pronounced in lower grades, indicating younger children are more susceptible to air pollution effects (Ransom & Pope, 1992). This association is also observed in Korea. Park, Lee, Ha, Lee, Kim & Hong (2002) analyzed the correlation between air pollutants and absenteeism among Korean elementary students. They found that only illness-related absences were associated with elevated levels of PM10, sulfur dioxide, and ozone (Park, Lee, Ha, Lee, Kim & Hong, 2002). When a child is ill and absent from school, it often falls on mothers to provide care, suggesting a close link between air pollution and mothers' daily activities.

An expanding body of literature explores air pollution's impacts on daily activities, predominantly focusing on Asian or Latin American countries with high pollution levels. 서미숙 (2015) analyzed PM10 concentration effects on hours worked and outdoor leisure time, considering gender and employment status. Employed women reduced work hours, and unemployed women decreased outdoor leisure time with rising PM10 levels (서미숙, 2015). However, no significant relationships were found for men, suggesting women may be more sensitive to PM10 pollution. 서미숙 (2015) did not confirm whether caregiving responsibilities influenced women's time allocation, as the presence of dependents was not identified. Aragón, Miranda & Oliva (2017) studied PM2.5 pollution's impact on labor supply in Peru, emphasizing caregiving's role. They noted a negative correlation between PM2.5 exposure and hours worked, particularly in households with young children and older adults, interpreting this as evidence that air pollution influences household decisions by affecting dependents' health and increasing caregiving demands (Aragón, Miranda

Figure 1. Average regional and monthly PM2.5 concentrations in 2021

(Unit: ㎍/㎥)



Source: Own elaboration based on the data of National Institute of Environmental Research (국립환경과학원, 2022, p.63, 150)

& Oliva, 2017).

When alternative caregiving arrangements exist, air pollution's effects on working hours can differ, as seen in China and Chile. Fan & Grainger (2019) found that higher PM2.5 levels were correlated with reduced weekly work hours in China, with no significant difference between parents and non-parents, likely due to prevalent grandparenting. Montt (2018) observed a similar trend in Chile, especially among women with children, attributed to the caregiving arrangements in Chile. The impact of air pollution on labor supply, especially through the caregiving channel, shows persistence over time. Kim, Manley & Radoias (2017) demonstrated that the air pollution from Indonesia's 1997 forest fires continued to affect work hours for respondents with dependents even three years later, particularly among women, and was not observed in those without dependents.

These studies suggest that caregiving significantly contributes to reduced working hours with increased air pollution. However, the question remains: does PM2.5 pollution indeed affect parental childcare time?

2. Measurements of childcare time

The question of how much time parents in Korea allocate to childcare is significant. To address this, it is crucial to define "childcare" clearly. Past research on parental childcare time often did not distinguish between different types of parent-child interactions (Nock & Kingston, 1988, p.61). However, the intriguing situation where increased maternal labor force participation seemed not to affect the time mothers spent with children led researchers to develop more nuanced measurements of childcare time (Bianchi, 2000, p.404). Bianchi (2000, p.412) emphasizes the importance of recognizing what is essential for children's well-being as an integral part of childcare. She suggests three specific measures for childcare time: primary childcare, secondary childcare, and time spent with children. Primary childcare involves direct caregiving activities, secondary childcare refers to caregiving as a background, and time spent with children includes any period where children are present, even if not actively engaged in the activities (Bianchi, 2000).

윤자영 (2018, p.174) defines childcare based on Reid's third-party criterion, considering activities that could be delegated to paid workers or replaced by market goods as forms of childcare (Reid, 1934, p.11). This definition implies that being attentive to children during other activities also constitutes childcare, as these responsibilities might be delegated in the parents' absence. 윤자영 (2018) measured Korean parents' childcare time using the Korean Time Use Survey, aligning with the categories by Bianchi (2000): direct childcare, indirect (simultaneous) childcare, and time spent with children. According to her findings, in 2014, Korean women with children under 10 spent an average of 161.6 minutes per day on direct childcare, 8.1 minutes on indirect childcare, and 127.9 minutes on time spent with children. Conversely, Korean men in similar situations spent an average of 39.6 minutes on direct childcare, 2.2 minutes on indirect childcare, and 86.4 minutes on time spent with children (윤자영, 2018).[2] These statistics reveal a substantial gender disparity in Korean domestic life, with women investing significantly more time in childcare. Men, in contrast, primarily engage in childcare by being with their children rather than participating directly in caregiving tasks. Despite an increase in men's involvement, women continue to manage more direct and routine caregiving activities. Interestingly, simultaneous caregiving time is relatively brief, suggesting either a lack of recognition for secondary caregiving tasks or a recall bias in reporting.

This study adopts three distinct measurements for

2) A similar trend is evident when comparing childcare time between dual-earner fathers and dual-earner mothers, highlighting a persistent gender gap, which will be discussed in more detail in the subsequent chapter.

assessing childcare time using the Korean Time Use Survey: Childcare Time as a Primary Activity (CPA), Childcare Time as a Simultaneous Activity (CSA), and Childcare Time in a Broader Context (CBC). Recognizing that childcare often coincides with other tasks, CSA reflects this multifaceted reality. The concept of childcare extends beyond direct tasks, encompassing the mental effort of attending to children's well-being. Therefore, CBC includes both physical and mental aspects of childcare. This comprehensive approach is pertinent for exploring whether PM2.5 pollution affects childcare time, considering that pollution-related child illnesses and reduced operational hours of educational institutions likely affect both direct caregiving and overall time spent with children. Furthermore, since respondents in the 2019 Korean Time Use Survey record their time spent using Information and Communications Technology (ICT) devices, such as smartphones, along with their activities involving these devices, this measurement provides the advantage of capturing parents' distant supervisory roles.

3. Gendered division of childcare time

Women, in general, tend to spend more time on childcare than men. The gendered division of unpaid wor k[3] including childcare can be understood through three main approaches: the rational choice approach, the relative resources approach, and the gender ideology approach. The rational choice approach, as proposed by Becker (1981), posits that the division of labor within families is a result of rational decision-making aimed at maximizing the household's overall productivity. In this model, married women often devote more time to unpaid work because their market wage rates tend to be lower than those of men, while their productivity in household tasks is greater than that of men (Becker, 1981, Enlarged Ed., 1991, p.42). Subsequent studies have further refined this approach by demonstrating that unpaid work is allocated rationally based on household members' availability of time (Coverman, 1985; Bianchi, Milkie, Sayer & Robinson, 2000). The relative resources approach suggests that the division of unpaid work reflects the resources that partners bring to their marriage. According to this approach, individuals with relatively fewer resources for negotiation, such as lower income or education, tend to perform more unpaid work (Hiller, 1984; Bianchi, Milkie, Sayer & Robinson, 2000). The gender ideology approach emphasizes that the division of unpaid work is influenced by societal gender norms rather than purely rational decisions within a family. This perspective asserts that individuals adopt traditional divisions of labor due to socialization, where men are expected to be breadwinners and women to be homemakers (Cunningham, 2001). Consequently, when couples divide labor, they often enact the gender norms prevalent in their society, a concept referred to as "doing gender" (West & Zimmerman 1987, p.137). According to this approach, individuals with more egalitarian gender role attitudes are likely to spend more time on unpaid work, and this association is especially strong among men (Blair & Lichter, 1991; Shelton & John, 1996).

Recent research on the division of unpaid work highlights two important points. First, there is a growing consensus that childcare and housework should be analyzed separately because these two domestic tasks exhibit distinct characteristics. Childcare is generally perceived as more enjoyable, rewarding, and desirable compared to housework (Gershuny, 2013; Sullivan, 2013). It appears that childcare is shared more equitably between partners than housework (김진욱, 권진, 2017; An, 2018; Zamberlan, Gioachin & Gritti, 2021). Consequently, the explanations offered by the three approaches may not

3) For the purpose of this chapter, the term "unpaid work" will be used to encompass both childcare and housework unless specific terminology is used in the original literature.

necessarily align with the actual practice when it comes to childcare.

Research on Korean women's involvement in unpaid work indicates that lower relative income and more traditional gender role attitudes are associated with increased time spent on housework, aligning with the relative resources and gender ideology approaches. However, these associations do not hold true for childcare (이태, 안준홍, 2022). In contrast to the rational choice approach, which posits that higher educational attainment should lead to reduced childcare time due to the expectation of higher market income, it is observed that parents with higher levels of education tend to invest more time in childcare. (주은선, 김사현, 김민성, 2014; García-Mainar, Molina & Montuenga, 2011). This discrepancy can be explained by the fact that childcare also includes an investment component, and high-quality childcare services may not be easily attainable in the market (García-Mainar, Molina & Montuenga, 2011). Therefore, educational level is better understood as an indicator of parents' commitment to their children's development and education rather than merely as a resource to negotiate away childcare responsibilities. 김진욱 & 권진 (2017) demonstrates that the factors influencing childcare time among Korean men have changed over time. In 2014, compared to 2004, the explanatory power of the dual-earner variable diminished, while the variable of gender role attitudes became significant in explaining married Korean men's childcare time. An (2018) investigated the gender division of childcare in Korea and found that the most significant difference between men and women lies in gender role attitudes. While no association is found between childcare time and gender role attitudes among women, men who hold more progressive gender role attitudes tend to have a higher share of childcare responsibilities. In summary, recent research suggests that educational level is a significant predictor of women's childcare time, while gender role attitudes play a pivotal role in men's childcare involvement.

Second, how additional childcare responsibilities are divided between men and women in response to unexpected situations is a significant question. We have recently experienced a powerful external shock worldwide, the Coronavirus disease (COVID-19) pandemic. Many countries implemented lockdowns and closed schools and childcare centers to mitigate the spread of the virus, and research on how parents adapted to these changes sheds light on whether the division aligns with the three previously discussed approaches. While some evidence supports the time availability and relative resources approaches, the most influential factor in the distribution of extra childcare during the pandemic was found to be gender norms (Zamberlan, Gioachin & Gritti, 2021; Del Boca, Oggero, Profeta & Rossi, 2022; Durante, Rodgers, Kaplowitz, Zundl, Ulu & Cohen, 2022; Smiljanić, Pepur & Bulog, 2023). This trend persisted even in countries with relatively high levels of gender equality, such as France. During the early months of the pandemic, going outdoors was viewed as potentially risky and associated with masculinity. As a result, women primarily assumed direct and routine caregiving responsibilities indoors, while men took on more indirect tasks like grocery shopping (Pasqualini, Dominguez-Folgueras, Ferragina, Godechot, Recchi & Safi, 2022, p.1029). It appears that during periods of crisis, traditional gender roles tend to resurface, and men and women revert to these roles despite progress in gender equality.

Detailed time-use surveys conducted during the pandemic reveal a gendered pattern in childcare responsibilities. With the closure of schools and childcare centers, both women and men reported an increase in time spent on childcare. However, women, on average, devoted an additional 5.2 hours per week to childcare, while men added 3.5 extra hours across 16 countries (UN Women, 2020).[4] In Korea, dual-earner mothers added 1.8 hours more to their daily childcare responsibilities, while dual-earner fathers added 0.8 hours (은기수, 2020, p.40). Data collected from 25 OECD countries during the

pandemic revealed that 76.9% of mothers who were not employed (but had working partners) reported undertaking most or all of the additional childcare, whereas only 24.5% of not employed fathers (with working partners) claimed the same (OECD, 2021). It is consistently observed that fathers' involvement in childcare depends on their partners' working arrangements. Fathers tend to spend relatively more hours on childcare only when their partners are unable to telework. However, mothers who work from home tend to take on the majority of additional childcare responsibilities, regardless of their partners' working arrangements (Boll, Müller & Schüller, 2021; Margaria, 2021; Del Boca, Oggero, Profeta & Rossi, 2022). This asymmetry suggests the presence of gendered dynamics in times of crisis.

4. Research question

This research pivots around the central question: does PM2.5 pollution influence the amount of time parents dedicate to childcare? While existing studies extensively document how air pollution diminishes individuals' work hours—especially for parents with young children—insights into its effects on non-market (unpaid) parental time remain scarce. This investigation seeks to discern if, and to what extent, types of parental childcare time are susceptible to fluctuations in PM2.5 pollution levels, with a keen interest in uncovering potential gender-specific impacts. Insights from studies conducted during the COVID-19 pandemic suggest a gendered allocation of additional childcare responsibilities in response to escalating PM2.5 pollution levels. Although the dynamics of prolonged pandemic lockdowns and daily PM2.5 pollution variations differ, they converge in imposing unexpected childcare demands, predominantly on mothers. Both scenarios—heightened pollution and pandemic conditions—can trigger health issues, necessitate confinement at home, and disrupt regular childcare facilities' schedules. Consequently, this study examines whether PM2.5 pollution's impact on parental childcare time exhibits gender disparities.

Ⅲ. Data and Methods

1. Data and sample

This study melds PM2.5 data with time-use statistics across Korea's 17 administrative regions for the year 2019. PM2.5 data, sourced from the Air Korea website—managed by the Korea Environment Corporation and accessed on November 17, 2022—comprises real-time air quality indicators. This system captures hourly readings of various air pollutants, including PM2.5, from 642 monitoring stations nationwide.

Parental childcare time information is derived from the 2019 Korean Time Use Survey's microdata, a quinquennial survey orchestrated by Statistics Korea, with the data also retrieved on November 17, 2022. The 2019 iteration of this survey spanned three distinct periods—July 19-28 for the first round, September 20-29 for the second round, and November 29-December 8 for the third round—to account for seasonal discrepancies, engaging roughly 29,000 individuals from 12,435 households. Employing a time diary methodology, the survey instructs participants to detail their primary and simultaneous activities, companionship, and other specifics in 10-minute intervals over 48 hours. Additionally, it encompasses diverse demographic and personal details, including income, educational background, employment status, and perspectives on gender roles. The survey's regional data, corresponding to 17 administrative divisions—encompassing seven metropolitan cities, eight provinces,

4) Korea stands out with the largest gap in childcare time between men and women among these 16 countries during the pandemic. Korean women spent an average of 34.1 hours per week on childcare, while Korean men spent 22.9 hours, which is more than 11 hours less than women. The average gap across the 16 countries was 7.2 hours (UN Women, 2020).

one special self-governing province, and one special self-governing city—were synchronized with the 642 PM2.5 monitoring stations' data. This integration was executed based on the respondents' dates[5] and regions.

Focusing on dual-income parents with at least one child younger than 10—typically those confronting the most acute time constraints—the sample was further streamlined to exclude households comprising extended family members, thereby eliminating potential childcare assistance from these individuals. The analysis prioritizes time-use data from weekdays, consolidating a total of 1,220 observations over two days from 610 respondents.

2. Measurements

This study delineates childcare time through three distinct lenses: Childcare Time as a Primary Activity (CPA), Childcare Time as a Simultaneous Activity (CSA), and Childcare Time in a Broader Context (CBC). CPA quantifies the daily minutes to primary childcare activities for children under 10, encompassing seven specific tasks ranging from physical care to educational engagement, as classified by the Korean Time Use Survey. This measure also accounts for travel time related to these children activities. CSA, on the other hand, captures the duration wherein childcare is a secondary task, performed alongside other primary activities. This time is discerned through respondents' notations of concurrent tasks. Lastly, CBC aggregates all childcare-related time, including moments spent in childrens' presence, regardless of active engagement, utilizing data on respondents' company during each activity.

The independent variables, average daily PM2.5 concentration, were calculated for both the survey day and the preceding day across Korea's 17 regions. For example, the PM2.5 concentration in Seoul on January 1 is the average value of 600 readings (24×25) measured hourly from 01:00 to 24:00 on January 1 at 25 PM2.5 monitoring stations in Seoul. These figures factor in immediate health impacts of PM2.5 exposure, particularly for vulnerable demographics. The study also integrates a gender variable to probe its direct and interactive effects on childcare time in relation to PM2.5 fluctuations.

Control variables encompass age, educational background, employment status, monthly income, relative income, children younger than six, gender role attitude, place of residence, region, survey round, and regional weather conditions. An overview of these variables is presented in <Table 1>.

3. Analytical strategy

This research adopts random effects Tobit models to elucidate the links between PM2.5 levels and childcare time. Tobit models are utilized when a dependent variable is continuous but subject to censoring at a certain threshold (e.g., zero in the case of time). Tobit models are ideal for this type of data as they handle restricted variance in the dependent variable and provide nonnegative fitted estimates (Wooldridge, 2012, p.597). Tobit models assume the presence of a latent dependent variable that exists for all observations and can theoretically assume values over its entire range, which includes negative values. However, due to censoring, observed values are truncated when they fall below a certain threshold, typically zero, and are recorded as zero. The actual observed outcome is only recorded when the latent variable exceeds this threshold (민인식, 최필선, 2015, p.122).

5) This study identified the survey's date using the survey round and day of the week information from the Korean Time Use Survey microdata. For overlapping days (Friday, Saturday, and Sunday) within one survey round, this study used the number of respondents per group to identify the corresponding day for each group—respondents to the survey were divided into five groups. Group A recorded their time use on Fridays and Saturdays, Group B on Sundays and Mondays, Group C on Tuesdays and Wednesdays, Group D on Thursdays and Fridays, and Group E on Saturdays and Sundays (통계청, 2019, p.16).

Table 1. Measurements of variables

Variable		Measure	Source
Dependent variable	Childcare time as a primary activity	Minutes per day spent on caregiving as a primary activity and traveling related to children	2019 Korean Time Use Survey
	Childcare time as a simultaneous activity	Minutes per day spent on caregiving as a simultaneous activity	
	Childcare time in a broader context	Minutes per day spent with children plus primary and simultaneous activity time	
Independent variable	PM2.5 concentration of the survey date	Average PM2.5 concentration over 24 hours of the survey date ($\mu g/m^3$)	Air Korea
	PM2.5 concentration of the day before the survey date	Average PM2.5 concentration over 24 hours of the day before the survey date ($\mu g/m^3$)	
Control variable	Gender	Male / Female	2019 Korean Time Use Survey
	Age	Years	
	Educational background	High school graduates or lower / College or university graduates / Higher than college or university graduates	
	Employment status	Regular workers / Temporary or daily workers / Self employed / Unpaid family workers	
	Monthly income[a]	Less than KRW 1 Million / 1M~2M / 2M~3M / 3M~4M / 4M~5M / 5M~6M / 6M~7M / 7M~8M / More than 8M	
	Relative income	Less than partner's income / Same / More than partner's income	
	Children under age 6	Yes / No	
	Gender role attitude[a]	Do you agree or disagree with the following statement? "A man's job is to earn money, and a woman's job is to look after the home and family." Strongly agree / Agree / Disagree / Strongly disagree	
	Place of residence	Eup · Myon-unit / Dong-unit	
	Region	Capital area / Chungcheong area / Jeolla area / Gangwon area / Gyeongsang area	
	Survey round	First / Second / Third	
	Rainfall	Yes (More than 0.1㎜) / No	Weather Data Service

Note: [a] The variables of monthly income and gender role attitude are used as continuous variables in regression models.

Recognizing the Korean Time Use Survey's two-day data collection framework, this study treats the information as panel data with a one-day interval, preserving the integrity of temporal relationships.[6] Random effects models, chosen for their capacity to discern both within- and between-unit effects and accommodate time-invariant variables, hinges on the assumption of no covariate-unit effect correlation (Clark & Linzer, 2012). In other words, estimators would not be consistent in the presence of omitted variables. To counteract potential omitted variable bias, the models integrate controls correlating with PM2.5 variability, including region, survey round, and rainfall, acknowledging the pollutant's sensitivity to these factors.

The analytical strategy further encompasses interaction terms between PM2.5 concentration and gender, probing the hypothesis of gender-conditioned PM2.5 impacts. All statistical computations were executed using Stata13 software.

6) Using only one day's data would result in a loss of information and could introduce issues in selecting which day's data to use.

Table 2. A Childcare time comparison between male and female

(Unit: Minute)

	Primary childcare	Simultaneous childcare	Childcare in a broader context
Male (n=610)	37.5 (51.4)	5.9 (16.7)	70.1 (79.0)
Female (n=610)	128.3 (92.0)	20.5 (31.8)	192.1 (123.9)
Total (n=1,220)	82.9 (87.3)	13.2 (26.4)	131.1 (120.5)

Note: Mean (Standard deviation)
Source: Own calculation based on the 2019 Korean Time Use Survey

Ⅳ. Results

1. Descriptive statistics

<Table 2> delineates the stark contrast in childcare time between male and female parents in dual-earner families, with children under 10, based on three childcare time metrics. The average values of CPA, CSA, and CBC among men are 37.5 minutes, 5.9 minutes, and 70.1 minutes a day, respectively. Men engage in childcare activities for just over an hour daily. In contrast, women spend 192.1 minutes a day with their children, with 128.3 minutes dedicated to CPA and 20.5 minutes to CSA. Women dedicate approximately three hours, a difference compared

Table 3. Descriptive statistics

Variable		Mean (SD), % (n=1,220)
PM2.5 concentration of the survey date		14.6 (3.6)
PM2.5 concentration of the day before the survey date		14.4 (5.0)
Age		38.7 (5.5)
Educational background	High school graduates or lower College or university graduates Higher than college or university graduates	26.7 66.6 6.6
Employment status	Regular workers Temporary or daily workers Self employed Unpaid family workers	66.2 13.0 17.9 3.0
Monthly income[a]	Less than KRW 1 Million / 1M~2M / 2M~3M 3M~4M / 4M~5M / 5M~6M 6M~7M / 7M~8M / More than 8M	11.5 / 19.3 / 28.4 20.5 / 11.6 / 5.6 0.8 / 0.7 / 1.6
Relative income	Less than partner's income Same More than partner's income	40.5 19.0 40.5
Children under age 6	Yes No	65.3 34.8
Gender role attitude[a]	Strongly agree / Agree Disagree / Strongly disagree	2.1 / 15.7 34.6 / 47.5
Place of residence	Eup · Myon-unit Dong-unit	21.0 79.0
Region	Capital area / Chungcheong area Jeolla area / Gangwon area / Gyeongsang area	29.2 / 20.0 19.7 / 4.6 / 26.6
Survey round	First / Second / Third	33.8 / 39.7 / 26.6
Rainfall	Yes / No	31.0 / 69.0

Note: [a] The variables of monthly income and gender role attitude are used as continuous variables in regression models.
Source: Own calculation based on the 2019 Korean Time Use Survey and the data of Air Korea

to men most pronounced in primary childcare activities. This discrepancy underscores women's more substantial involvement, both in terms of duration and intensity. Interestingly, simultaneous childcare activities, though expected to be prevalent given the time constraints in dual-earner families, are scarcely reported, suggesting an underrepresentation in the survey data.

<Table 3> provides summary statistics for the independent and control variables used in the analysis. The average PM2.5 concentrations of the survey date and the day before are approximately 14 ㎍/㎥, which is lower than the national average PM2.5 concentration for 2019 across the country, which was 23 ㎍/㎥. This could be because the first and second rounds of the survey were conducted in July and September when PM2.5 pollution tends to decrease. The gender ratio is balanced since the sample includes men and women from 305 dual-earner families. The average age of respondents is 38.7 years old. Around 66% of respondents are college or university graduates, and a similar percentage are regular workers. The most common monthly income falls within the range of 2-3 million KRW, accounting for 28.4% of respondents, followed by the 3-4 million KRW range. In many cases, respondents' income differs from that of their partner, with most men reporting higher incomes than their partners (or conversely, most women reporting lower incomes than their partners). Two-thirds of respondents have children under six. More than 82% of respondents disagreed with the statement that "A man's job is to earn money, and a woman's job is to look after the home and family," indicating more progressive gender role attitudes. About 79% of respondents live in Dong-unit areas, indicating a higher proportion of urban residents compared to rural areas. The largest number of respondents reside in the capital region (29.2%), while the Gangwon region has the smallest representation (4.6%). A relatively larger number of respondents participated in the first and second rounds of the survey. On 31% of the survey days, there was rainfall.

2. Regression Analyses

<Table 4> presents regression analysis results. Models 1, 3, and 5 were designed to examine the main effects of the independent and control variables, while Models 2, 4, and 6 assessed the moderating effects of gender. The likelihood-ratio test was performed, concluding that it is more appropriate to use random effects Tobit models rather than pooled Tobit models in all of the models.

The PM2.5 concentrations of the survey date and the day before had no significant effect on CPA (Model 1), CSA (Model 3), and CBC (Model 5). However, a nuanced picture emerges when considering gender as a moderating factor, with increased PM2.5 levels correlating with more time women spend on childcare activities. For women, when the PM2.5 concentration of the survey date increases by one ㎍/㎥, the time spent on CPA increases by 2.654 minutes (Model 2), CSA increases by 2.560 minutes (Model 4), and CBC increases by 3.306 minutes (Model 6).[7] The gender-differentiated responses are visualized in Figure 2, which illustrates the changes in childcare time as the PM2.5 concentration of the survey date rises, while keeping the other variables at their average values. It is evident that the slopes vary between genders, underscoring societal norms dictating childcare responsibilities, particularly during environmental crises. These findings resonate with existing literature on reduced working hours for women during high pollution periods, suggesting a compensatory increase in childcare investment. Further analysis is needed to determine which specific activities increase the additional childcare time, but potential activities include washing

7) Note that the Tobit coefficients estimate the linear increase in the latent variable, not the observed outcome, for each unit increase in the explanatory variables (Wooldridge, 2012, p.598). Among the observed outcomes of the childcare time variables, the marginal effects are as follows: 2.027 minutes for Model 2 ($p<.05$), 0.709 minutes for Model 4 ($p<.05$), and 2.655 minutes for Model 6 ($p<.1$). The marginal effects of all other variables are presented in an appendix.

children more thoroughly, nursing sick children, or engaging in indoor play with children.

The variables of gender, age, education background, working status, relative income, the presence of children under six years old, and region significantly influenced CPA (Model 1). The descriptive statistics revealed a notable disparity in the childcare time between women and men. Holding other variables constant, women dedicated 82.715 more minutes (65.725 more minutes among the actual observed outcomes) to CPA compared to men. Childcare time tends to decrease as parents' age increases. This trend may be attributed to the fact that older parents are likely to have older children who require less care. There was a noteworthy increase in childcare time among college or university graduates and parents with higher educational level compared to those with a high school degree or lower education. This finding aligns with previous research, indicating that higher educational levels correlate with increased interest in children's development and education, leading to a greater investment of time in childcare.

Table 4. Results of random effects Tobit Models: effects of PM2.5 concentration on childcare time

Variable		Primary childcare		Simultaneous childcare		Childcare in a broader context	
		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
PM2.5 concentration of the survey date		.010 (.616)	-1.440 (.894)	-.039 (.579)	-1.712† (.960)	-.808 (.843)	-2.547* (1.197)
PM2.5 concentration of the day before the survey date		-.175 (.507)	-.657 (.730)	-.068 (.458)	-.522 (.725)	-.363 (.680)	-.654 (.948)
Gender (Ref=Male)	Female	82.715*** (9.362)	30.935 (20.938)	36.933*** (7.360)	-10.633 (19.415)	93.009*** (11.914)	36.224 (27.965)
Gender*PM2.5 (Ref=Male)	Female	-	2.654* (1.183)	-	2.560* (1.162)	-	3.306* (1.613)
Gender*previous PM2.5 (Ref=Male)	Female	-	.862 (.937)	-	.703 (.868)	-	.555 (1.246)
Age		-1.722** (.624)	-1.729** (.622)	-.189 (.488)	-.179 (.486)	-3.001*** (.799)	-3.009*** (.796)
Educational background (Ref=High school graduates or lower)	College or university graduates	19.548** (7.252)	19.956** (7.231)	2.611 (5.640)	3.093 (5.621)	28.759** (9.226)	29.254** (9.196)
	Higher than college or university graduates	36.978** (13.791)	37.391** (13.746)	4.835 (10.967)	5.431 (10.910)	40.733* (17.706)	41.118* (17.644)
Employment status (Ref=Regular workers)	Temporary or daily workers	26.637** (9.793)	26.590** (9.763)	1.313 (7.287)	1.188 (7.251)	30.883* (12.609)	30.916* (12.566)
	Self employed	21.950** (8.259)	22.200** (8.235)	10.383 (6.433)	10.878† (6.411)	28.598** (10.509)	29.074** (10.473)
	Unpaid family workers	43.274* (18.845)	43.076* (18.785)	8.839 (13.735)	8.357 (13.672)	59.332* (24.379)	59.296* (24.294)
Monthly income[a]		-3.592 (2.643)	-3.534 (2.636)	-1.521 (2.103)	-1.558 (2.097)	-6.441† (3.359)	-6.354† (3.348)
Relative income (Ref=Less than partner's)	Same	-15.707 (9.551)	-16.364† (9.523)	-10.230 (7.268)	-10.758 (7.235)	-26.045* (12.251)	-26.763* (12.214)
	More than partner's	-22.453* (11.233)	-23.743* (11.215)	-14.173 (8.909)	-15.275 † (8.900)	-29.314* (14.333)	-30.514* (14.307)
Children under age 6 (Ref=No)	Yes	57.010*** (7.029)	57.018*** (7.006)	1.902 (5.404)	2.124 (5.384)	52.965*** (8.863)	52.972*** (8.830)
Gender role attitude[a]		2.511 (4.142)	2.445 (4.131)	.239 (3.254)	.159 (3.246)	5.595 (5.258)	5.566 (5.242)
Place of residence (Ref=Eup · Myon)	Dong-unit	10.243 (7.920)	10.393 (7.894)	7.282 (6.208)	7.456 (6.178)	16.343 (10.120)	16.501 (10.084)

Table 4. Results of random effects Tobit Models: effects of PM2.5 concentration on childcare time(cont.)

Variable		Primary childcare		Simultaneous childcare		Childcare in a broader context	
		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Region (Ref=Capital area)	Chungcheong area	-7.437	-7.425	2.249	1.943	-16.028	-15.996
		(9.184)	(9.157)	(7.318)	(7.300)	(11.680)	(11.638)
	Jeolla area	-4.605	-4.659	5.768	5.513	-6.304	-6.270
		(9.235)	(9.191)	(7.313)	(7.290)	(11.748)	(11.705)
	Gangwon area	27.805†	27.627†	25.304*	24.683*	25.298	25.305
		(15.712)	(15.663)	(11.884)	(11.818)	(20.233)	(20.162)
	Gyeongsang area	-5.344	-5.350	16.656*	16.397*	-15.326	-15.320
		(8.446)	(8.419)	(6.635)	(6.607)	(10.796)	(10.758)
Survey round (Ref=First)	Second	1.929	1.786	-9.394	-9.590	-3.309	-3.384
		(7.977)	(7.952)	(6.318)	(6.299)	(10.239)	(10.206)
	Third	8.792	8.828	-3.875	-3.895	-7.229	-7.216
		(8.330)	(8.298)	(6.555)	(6.515)	(10.689)	(10.650)
Rainfall (Ref=No)	Yes	-1.535	-1.511	4.040	4.169	3.041	3.040
		(5.382)	(5.365)	(4.710)	(4.704)	(7.198)	(7.187)
Constant		42.749	71.656*	-40.544	-9.636	157.319***	187.329***
		(34.952)	(36.410)	(27.633)	(29.916)	(44.698)	(46.621)
Number of observations		1,220	1,220	1,220	1,220	1,220	1,220
Wald chi-square		506.67***	516.18***	113.83***	118.46***	466.72***	474.86***

Note: 1) †p<.1, * p<.05, ** p<.01, *** p<.001
2) [a] Higher values indicate higher income levels and more egalitarian gender role attitudes.
Source: Own calculation based on the 2019 Korean Time Use Survey and the data of Air Korea

Employment status also played a role, with temporary or daily workers, self-employed, and unpaid family workers spending more time caring for their children compared to regular workers. This difference may be attributed to the flexibility in working hours enjoyed by these occupational groups, as opposed to the fixed schedules of regular workers. Parents with higher income than their partner spent less time caring for their children than those with lower income relative to their partner. This could be interpreted as these individuals utilizing their income as a negotiation resource or dedicating more hours to their work than their partner. Parents with children under six years old allocated more time to childcare than those without such young children. This disparity likely arises from the greater need for parental care and attention among younger children. Lastly, residents of the Gangwon area devoted more time to childcare than those in the capital area. This discrepancy may be attributed to the number of children under six years old per household. When comparing the number of children under six per household by area, the Gangwon area stands out as the only area among the five, with more than one, specifically at 1.1, while the capital area is 0.9. Given that the number of younger children significantly influences physical care time, it appears that, even after controlling for the presence of children under six, the Gangwon area's CPA remains longer than that of the capital area.[8)]

CSA was found to be associated with gender and region (Model 3). Women's childcare time exceeded that of men by 36.933 minutes (11.495 minutes among the actual observed outcomes), and residents of the Gangwon and Gyeongsang areas exhibited longer childcare times when

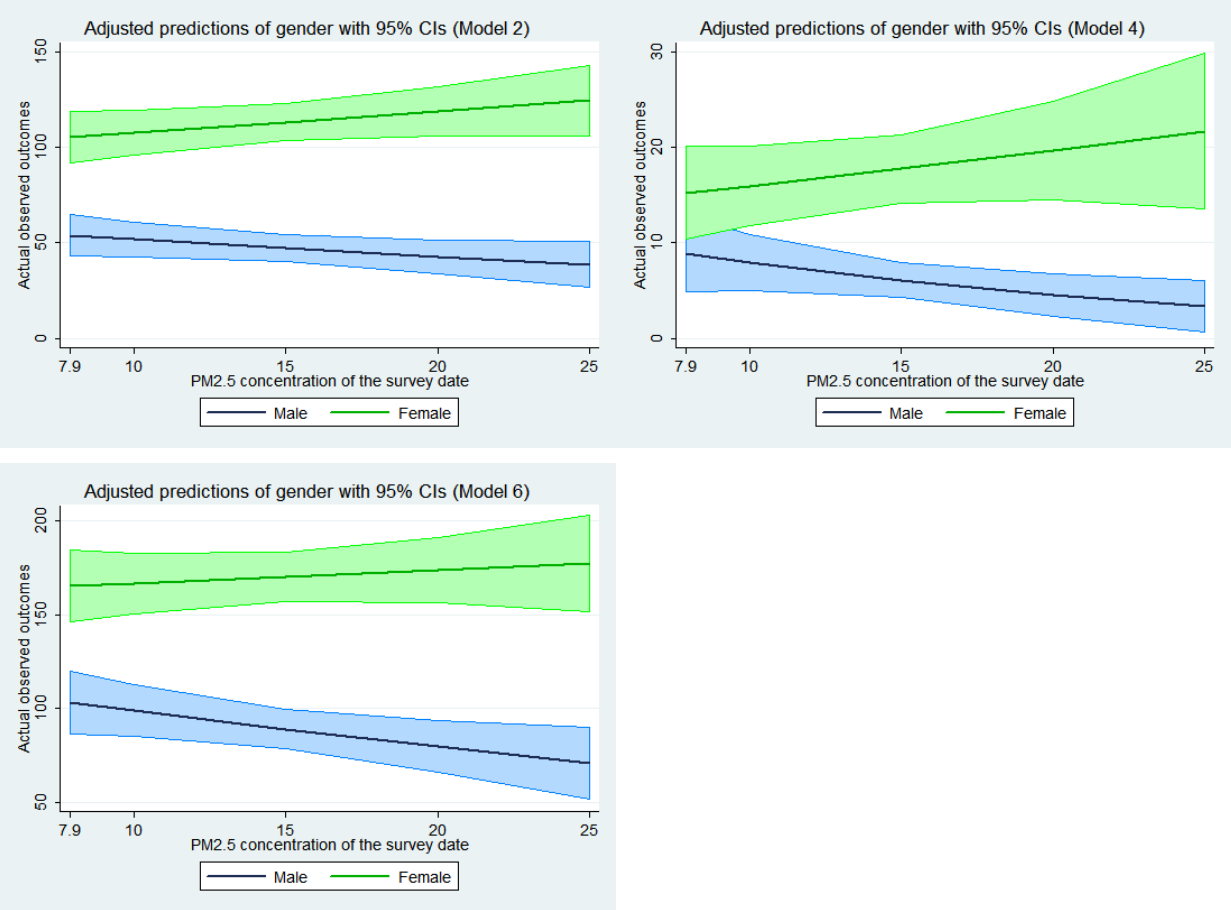
8) Among the Gangwon area's CPA, the average time devoted to physical care is 51 minutes—the longest among the five areas, 13 minutes more than the 38 minutes in the capital area, which significantly contributes to the 19-minute difference in CPA between the two areas. Physical care encompasses fundamental care activities such as washing and feeding, with the time increasing for younger children.

compared to those in the capital area. There are many facets of CSA that are not explained by the approaches examined in the literature review, apart from gender. It is anticipated that parents whose children are in urgent need of care and who find themselves juggling self-care and childcare will spend more time on CSA. In light of this assumption, it becomes apparent that women experience greater time constraints compared to men.

CBC was found to be associated with gender, age, educational background, employment status, monthly income, relative income, and the presence of children under six years old (Model 5). These findings mirror the results for Model 1, as the CBC encompasses both time spent on primary and simultaneous activity. Therefore, the majority of variations in the dependent variable stems from the changes in CPA and CSA. To put it differently, as PM2.5 concentration rises, the time spent on direct care work increases, which naturally leads to the increase in time spent with children. One notable difference lies in the significance of monthly income; higher monthly income was correlated with less overall time spent with children, possibly because individuals with higher incomes tend to have longer working hours and, as a result, less time available for childcare.

Interestingly, the gender role attitude variable did not significantly influence childcare time in any of the models (Models 1, 3, and 5), hinting at the pervasiveness of traditional gender roles in childcare, irrespective of individual beliefs. This insight underscores the societal expectation burdening women with primary caregiving

Figure 2. Childcare time for males and females by PM2.5 concentration of the survey date



Source: Own elaboration based on the 2019 Korean Time Use Survey and the data of Air Korea

responsibilities, especially during environmental or health emergencies.

V. Conclusion

Our daily lives are gradually changing due to the increasing problem of PM2.5 pollution. Air purifiers have become essential home appliances, and facial masks will continue to be worn even after the COVID-19 pandemic has subsided. On days when the concentration of PM2.5 is high, businesses emitting PM2.5-generating substances must suspend operations as part of emergency reduction measures. To safeguard children's health, who are particularly vulnerable to air pollution, childcare centers, kindergartens, and elementary schools may temporarily close or adjust their operating hours. Both of these actions can result in reduced working hours for workers, especially those with young children. Existing studies have empirically demonstrated that air pollution reduces the worked hours of women with young children. However, no research has yet explored whether parental childcare time actually increases in proportion to the reduced worked hours.

This study analyzed the impact of PM2.5 concentration on childcare time by combining data from the 2019 Korean Time Use Survey and PM2.5 concentration data provided by Air Korea. The analysis focused on dual-earner couples with young children, who typically experience the most time pressure. Various types of childcare were considered, and childcare time was measured in three ways: CPA, CSA, and CBC. The study emphasized that care work is gendered in families and explored whether gender moderates the relationship between PM2.5 concentration and childcare time. The main results are as follows: PM2.5 concentrations of the survey date and the day before were found to be unrelated to the three types of childcare time. However, the PM2.5 concentration of the survey date had different effects on childcare time depending on gender. As the PM2.5 concentration rose, women's childcare time increased, and this moderating effect of gender was observed across CPA, CSA, and CBC.

What do these results mean? First, they indicate that PM2.5 pollution affects everyone equally, but its impacts vary. In Korean society, where traditional gender roles are deeply ingrained, women take on the primary responsibility for caregiving. In line with these traditional gender norms, women bear a disproportionate share of the increased caregiving burden during high pollution periods. This suggests that the environmental problem of air pollution can potentially reinforce existing traditional gender norms. Furthermore, as PM2.5 concentration increases, women tend to allocate more time to caring for their children as a simultaneous activity, seemingly in response to the sudden surge in childcare demands. The more they attempt to juggle multiple tasks, the greater the pressure and fatigue they experience, making it challenging to provide undivided attention to caregiving. Air pollution can result in heightened fatigue among women, which may lead to low quality childcare.

Second, it was observed that as PM2.5 concentration rose, men decreased their childcare time (as evident in Figure 2 where men's slopes descend to the right). The decrease in childcare time implies an increase in time for other activities, with the most likely option being an increase in working hours. Montt (2018) found that PM2.5 concentration exhibited a negative correlation with women's worked hours and a positive correlation with men's worked hours. He offers two interpretations of these findings. One involves scenarios in which female workers leave work early to care for a sick child, while their partner typically works late. Another entails male workers extending their working hours when female workers leave the workplace early (Montt, 2018, p.9).[9] Drawing from Montt's (2018) study, the reduction in men's childcare time in this study can be attributed to their decision to work longer hours, instead of women. It becomes challenging for women to establish a stable career in the labor market by choosing to take on caregiving responsibilities, while men have less time

available to spend with their children by choosing to work longer hours. This aligns with the conclusion reached by Pasqualini, Dominguez-Folgueras, Ferragina, Godechot, Recchi & Safi (2022) that, although stemming from different causes, both men and women reinforce traditional gender role attitudes in response to the crisis.

Third, interestingly, it was observed that women were more significantly impacted by the PM2.5 concentration of the survey date compared to that of the day before the survey date. Previous studies examining the relationship between air pollution and working hours assumed a time lag between air pollution exposure and its effects on work, typically measuring these variables with a time gap ranging from one day to one week. Consequently, a limitation of these studies is the difficulty in understanding the immediate impact of air pollution. The findings of this study reveal that women exhibit heightened sensitivity to the present PM2.5 concentration and respond promptly. During the study period, the PM2.5 concentration remained below 35 ㎍/㎥, the threshold of moderate level, making it unlikely that childcare centers and schools shortened their operating hours. Nevertheless, the observed increase in childcare time correlating with the PM2.5 concentration of the survey date suggests that mothers proactively responded to the forecasted PM2.5 concentration by engaging in more indoor activities with their children, and so forth.

Based on the results and discussions, this study proposes the following policy and methodological implications. The research findings unveiled that PM2.5 pollution reinforces traditional gender roles in childcare. Conversely, this implies that policies addressing PM2.5 pollution can potentially reduce the gender gap. However, the temporary closures of childcare centers and other facilities that can be implemented during emergency reduction measures only increase distrust among working mothers that the Korean government is encouraging gender inequality. Policymakers should acknowledge that air pollution response and reduction policies may inadvertently exacerbate the gender gap. Therefore, they should proactively implement measures to address and reduce air pollution, all while carefully designing, implementing, and monitoring policies to ensure they do not introduce gender-unequal elements. A gender perspective should be seamlessly integrated into policies aimed at reducing air pollution (e.g., minimizing the use of fossil fuels), mitigating the impact of air pollution exposure (e.g., installing air purification systems in all childcare centers), and providing support for situations when the demand for childcare increases due to air pollution (e.g., guaranteeing emergency care leave).

Regarding methodology, the Korean Time Use Survey needs to provide more detailed regional data than simply distinguishing among the 17 administrative regions. PM2.5 concentration is influenced by a variety of factors, including weather and geography, which means that concentration levels may differ even within a single administrative region. Enhanced regional specification is essential to enable meaningful quantitative analysis. Ultimately, it is imperative to develop datasets that encompass both environmental and social information. This study underscores that environmental issues have repercussions beyond their environmental aspects. To effectively address the social problems arising from environmental issues, it is crucial to prioritize research grounded in empirical data. To facilitate comprehensive research that bridges the realms of the environment and society and to prepare effective countermeasures, it is essential to create datasets that seamlessly integrate both environmental and social information.

This study is the first to analyze the relationship between PM2.5 pollution and childcare time. The subjects of the study are exclusively dual-earner couples with young

9) The former situation can occur in the household when a married couple operates a self-employed business together, while the latter can take place at the workplace when male colleagues compensate for the reduced working hours of female colleagues to meet their daily workload targets.

children, as they are expected to experience the most time pressure. Nevertheless, it is important to note that within dual-earner households, responses to PM2.5 pollution may vary depending on childcare arrangements. To provide more sophisticated and actionable policy implications, future research should explore the impact of PM2.5 pollution while categorizing childcare arrangements. Furthermore, it is crucial to compare and analyze the impact of PM2.5 pollution based on household characteristics, including various household types such as single-income households and single-parent households.

Given that each day is limited to 24 hours, any adjustments in one activity's duration will inevitably affect the time available for other activities. This study assumed that there would be a trade-off relationship between childcare time and paid work time. However, in reality, various patterns of time reallocation may occur in response to PM2.5 pollution. Therefore, future research should investigate changes in childcare time in relation to other activities, such as paid work, housework, and leisure time, and changes within childcare time, such as the impact on indoor and outdoor care time. Additionally, given that the Korean government is issuing a half-day forecast and the PM2.5 level tends to be higher in the morning due to air stagnation, future research can consider measuring the PM2.5 level twice daily.

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Appendix

Table A1. Marginal effects of Tobit Models

Variable		Primary childcare		Simultaneous childcare		Childcare in a broader context	
		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
PM2.5 concentration of the survey date		.008 (.495)	-.091 (.497)	-012 (.178)	-.132 (.186)	-.706 (.737)	-.781 (.738)
PM2.5 concentration of the day before the survey date		-.141 (.408)	-.182 (.410)	-.021 (.141)	-.052 (.146)	-.317 (.594)	-.329 (.595)
Gender (Ref=Male)	Female	65.725*** (7.271)	65.248*** (7.259)	11.495*** (2.326)	11.385*** (2.305)	80.576*** (10.159)	80.133*** (10.137)
Gender*PM2.5 (Ref=Male)	Female	-	2.027* (.918)	-	.709* (.351)	-	2.655† (1.377)
Gender*previous PM2.5 (Ref=Male)	Female	-	.606 (.725)	-	.183 (.267)	-	.405 (1.062)
Age		-1.386** (.502)	-1.393** (.501)	-.058 (.150)	-.055 (.149)	-2.622*** (.698)	-2.632*** (.696)
Educational background (Ref=High school graduates or lower)	College or university graduates	15.326** (5.568)	15.653** (5.552)	.792 (1.691)	.930 (1.666)	24.671** (7.782)	25.108** (7.758)
	Higher than college or university graduates	30.061* (11.656)	30.413** (11.629)	1.501 (3.505)	1.673 (3.474)	35.414* (15.768)	35.761* (15.722)
Employment status (Ref=Regular workers)	Temporary or daily workers	21.827** (8.291)	21.804** (8.270)	.391 (2.190)	.351 (2.157)	27.231* (11.341)	27.276* (11.309)
	Self employed	17.824** (6.871)	18.050** (6.862)	3.394 (2.228)	3.549 (2.223)	25.158** (9.393)	25.604** (9.373)
	Unpaid family workers	36.503* (16.876)	36.354* (16.827)	2.844 (4.776)	2.657 (4.683)	53.641* (22.935)	53.635* (22.864)
Monthly income[a]		-2.891 (2.128)	-2.847 (2.124)	-.469 (.648)	-.477 (.642)	-5.628† (2.935)	-5.557† (2.928)
Relative income (Ref=Less than partner's)	Same	-12.859† (7.798)	-13.426† (7.792)	-3.321 (2.356)	-3.493 (2.346)	-22.933* (10.758)	-23.595* (10.739)
	More than partner's	-18.119* (9.049)	-19.176* (9.040)	-4.426 (2.783)	-4.742† (2.765)	-25.716* (12.556)	-26.788* (12.542)
Children under age 6 (Ref=No)	Yes	43.828*** (5.128)	43.874*** (5.114)	.583 (1.645)	.646 (1.626)	45.276*** (7.397)	45.318*** (7.375)
Gender role attitude[a]		2.021 (3.333)	1.970 (3.327)	.074 (1.002)	.049 (.994)	4.889 (4.594)	4.868 (4.584)
Place of residence (Ref=Eup·Myon)	Dong-unit	8.136 (6.206)	8.261 (6.189)	2.148 (1.751)	2.182 (1.727)	14.121 (8.641)	14.267† (8.615)
Region (Ref=Capital area)	Chungcheong area	-5.954 (7.333)	-5.951 (7.319)	.609 (1.992)	.523 (1.974)	-13.981 (10.155)	-13.964 (10.127)
	Jeolla area	-3.710 (7.416)	-3.757 (7.399)	1.624 (2.082)	1.544 (2.063)	-5.559 (10.348)	-5.534 (10.319)
	Gangwon area	23.780† (13.833)	23.644† (13.797)	8.724† (4.814)	8.447† (4.741)	22.978 (18.636)	23.000 (18.583)
	Gyeongsang area	-4.298 (6.793)	-4.308 (6.778)	5.264* (2.111)	5.159* (2.093)	-13.380 (9.421)	-13.385 (9.395)
Survey round (Ref=First)	Second	1.538 (6.358)	1.426 (6.344)	-2.899 (1.971)	-2.941 (1.952)	-2.902 (8.981)	-2.969 (8.959)
	Third	7.114 (6.745)	7.152 (6.728)	-1.264 (2.133)	-1.265 (2.111)	-6.311 (9.327)	-6.305 (9.301)
Rainfall (Ref=No)	Yes	-1.234 (4.321)	-1.216 (4.311)	1.264 (1.498)	1.297 (1.488)	2.660 (6.305)	2.662 (6.301)

Note: 1) †p<.1, * p<.05, ** p<.01, *** p<.001

2) [a] Higher values indicate higher income levels and more egalitarian gender role attitudes.

Source: Own calculation based on the 2019 Korean Time Use Survey and the data of Air Korea

초미세먼지가 자녀 돌봄 시간에 미치는 영향:
대기오염의 젠더 효과

최 미 향[1]

[1] 한국사회복지협의회

초 록

이 연구는 초미세먼지가 부모의 자녀 돌봄 시간에 영향을 미치는지, 특히 초미세먼지의 영향이 엄마와 아빠에게 똑같이 나타나는지를 살펴본다. 초미세먼지는 어린아이의 건강을 위협하고, 보육교육기관 운영 시간을 단축시킬 수 있어 초미세먼지 농도가 높아질수록 자녀 돌봄 시간이 늘어날 것으로 예상할 수 있다. 이 연구는 2019년 생활시간조사와 초미세먼지 농도 데이터를 결합한 자료를 확률효과 토빗 모형을 사용하여 분석하였다. 분석 결과, 초미세먼지 농도와 부모의 자녀 돌봄 시간 사이에는 유의한 관계가 발견되지 않았으나, 엄마와 아빠에게 초미세먼지 농도는 다른 영향을 미치는 것으로 나타났다. 초미세먼지 농도가 올라갈수록 엄마의 주행동 돌봄 시간, 동시행동 돌봄 시간, 넓은 의미의 돌봄 시간 모두 늘어났다. 반대로 아빠의 돌봄 시간은 감소하였다. 결론에서는 초미세먼지가 자녀 돌봄에서의 성 불평등을 강화할 수 있음을 논의하고, 정책 및 방법론적 함의, 추후 연구 과제를 제시하였다.

주요 용어: 초미세먼지, 자녀 돌봄 시간, 젠더 효과, 생활시간조사