

Theoretical basis and analytical framework for the impact of air pollution on the labor supply of middle-aged and elderly people in rural areas

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Abstract: *Starting from the health of rural residents, a theoretical analysis framework of "air pollution - farmers' health level - rural labor supply" is constructed to clarify the inherent logical relationship and mechanism of air pollution, health loss, and labor supply. This article applies clinical medical theory to the study of rural labor supply, combining the theory of large human capital and the theory of health demand, expanding the scope of application of relevant theories. Current research on air pollution and labor supply mostly focuses on cities as research areas, lacking research on rural areas. This article will extend the study of tentacles to rural areas, based on human capital theory, and construct an analytical framework from the micro individual level to investigate the loss of health human capital of rural residents exposed to air pollution, and explore the agricultural labor supply losses caused by health problems. Using Grossman's health needs theory, this study analyzes the impact and mechanism of ambient air pollution on the health human capital of rural mid-aged and elderly, enriching the theoretical research on rural labor supply.*

Keywords: *air pollution; Resident labor supply; Theoretical foundation; analytical framework*

1. Introduction

At present, various types of environmental pollution and ecological damage are showing a high incidence trend, becoming a national injury and a pain for people's livelihoods. Among various environmental pollution issues, air pollution is particularly prominent. The 2022 China Ecological Environment Status Bulletin pointed out that in 2022, out of 339 prefecture level and above cities in China, 126 cities still exceeded the standard for environmental air quality, accounting for 37.2%^[1]. Air pollution not only hinders the sustainable development of the economy and society, but also seriously threatens the physical health of residents^[2]. According to the Global Burden of Disease Report released by the World Health Organization (WHO), in 2017, 161.1 out of every 100000 deaths in China were caused by diseases related to air pollution^[3]. In addition, air pollution can also affect individual labor supply behavior^[4], labor regional reallocation^[5], labor productivity, and human capital efficiency^[6].

Clinical medicine has shown that cardiovascular and chronic respiratory diseases caused by air pollution can be accompanied by symptoms such as headache, limb weakness, cough, chest tightness, shortness of breath, or difficulty breathing^[7]. Although long-term bed rest is not necessary, the resulting health loss can weaken the productivity of workers and prompt them to reduce their labor supply time. For manual laborers, healthy human capital is a key factor in obtaining remuneration in the labor market^[8,9]. Impaired health will directly reduce work efficiency and shorten working hours^[10]. Within a certain time frame, rational economic agents achieve utility maximization by continuously adjusting the time allocation of leisure, market labor, and household labor. However, diseases can shorten the supply time of labor that maximizes utility, and even force workers to completely withdraw from the labor market, resulting in regional human capital loss. Therefore, formulating rigorous environmental regulations and policies, adopting strict pollution control measures, and formulating effective medical security policies are important means to protect the ecological environment, improve public health, and ensure sufficient supply of human capital. They are the focus of attention for every country and every era, and also the historical proposition faced by China under the concept of people-oriented development.

Healthy human capital provides a solid foundation and sustainable driving force for economic development. Air pollution can affect individual health levels, have an impact on their labor supply

behavior and decision-making, and thus affect economic and social development. Our country's economy has entered a critical stage of shifting from high-speed growth to high-quality development, and the problems of labor shortage and insufficient supply are posing challenges to economic development. Against the backdrop of the disappearing demographic dividend, aging labor force, and "low-end lock-in", continuously improving healthy human capital and labor supply efficiency is a powerful support for promoting the steady development of the labor market and high-quality economic development. This article is based on the health demand function and work leisure model in the field of economics, and constructs a theoretical analysis framework of "air pollution - health depreciation - labor supply". Combining knowledge and methods from public health and medical fields, it reveals the inherent mechanism of air pollution on residents' health and labor supply behavior, thus making useful supplements to existing relevant literature.

2. Theoretical basis

2.1 Pathological basis of health loss caused by air pollution

Fine particulate matter (PM_{2.5}) in the air affects the cardiovascular and respiratory systems of the human body through the following three pathways. Firstly, soluble components in fine particulate matter, such as metal and organic molecules, directly enter the human circulatory system; Secondly, lung cells release pro-inflammatory mediators and vasoactive molecules into the bloodstream, causing systemic oxidative stress and inflammatory reactions; Thirdly, ultra fine particles are prone to enter the alveoli and can even pass through the Qi blood barrier and blood-brain barrier, affecting blood and nervous system function^[11]. PM_{2.5} in the air can directly affect the cardiovascular system and blood, and can also cause systemic inflammation through oxidative stress and inflammatory reactions in the lungs. Firstly, oxidative stress is a process of aging and disease caused by free radicals in the body. PM_{2.5} has the activity of free radicals and can act on alveolar epithelial cells and macrophages, catalyzing or inducing intracellular reactive oxygen species (ROS) and reactive nitrogen species (RNS), increasing their content, attacking biomolecules such as DNA, RNA, proteins, and cell membrane lipids, inducing gene mutations or leading to lipid peroxidation damage to the cell membrane. In addition, due to its large specific surface area, PM_{2.5} can adsorb a large amount of toxic substances such as heavy metal elements and organic matter, directly causing oxidative damage to cells or DNA. Secondly, PM_{2.5} can directly or indirectly act on inflammatory cells in the body, inducing the expression and release of various inflammatory and chemical factors, leading to the occurrence of local tissue or systemic inflammation^[12-14].

2.2 Human Capital Theory

The research on human capital theory can be traced back to the mid to late 17th century. The historical evolution of theoretical development can be divided into three stages: early human capital theory, contemporary Western human capital theory, and new developments in human capital theory, as follows:

2.2.1 Early Human Capital Theory

The study of human capital theory can be traced back to 1664, with the most representative work being "On Taxation", in which the author proposed that "land is the mother of wealth, and labor is the father of wealth". This argument highly affirms the economic value generated by laborers through labor, which is widely recognized as an early human capital theory^[15]. In 1776, Adam Smith systematically discussed the issue of human capital in his book "The Wealth of Nations", proposing that investment in education and training can generate high returns and that compulsory basic education is necessary^[16]. Based on Adam Smith's viewpoint, John Stuart Mill proposed that human capital is an important component of a country's wealth, and education and training are effective ways to improve labor productivity. The government should undertake the task of establishing education^[17]. Alfred Marshall believed that individual expenditure on education and training was an investment, and that individuals could not afford all the costs of education and training^[18]. In order to create a virtuous cycle in the social economy, governments and entrepreneurs should develop the education industry. In summary, early human capital theories mainly emphasized the important role of human capital in promoting economic development, and education and training were important means of accumulating human capital.

2.2.2 Contemporary Western Human Capital Theory

With the further development of human capital theory, Theodore W. Schultz first systematically proposed the theory of human capital in 1960. He clearly pointed out that the accumulation of human capital is the main source of socio-economic growth, and the rate of return of human capital is higher than that of material capital^[19]. Among the various factors that affect economic development, human factors are the most crucial. Economic development mainly depends on the improvement of human quality, rather than the abundance of natural resources or the amount of capital. Schultz believes that human capital is a type of capital reflected in workers, expressed in terms of the quantity and quality of workers, that is, the total value of workers' knowledge level, technical level, work ability, and health status. In the process of forming human capital, investment is crucial, and human capital can be understood as capital formed by investing in human resources, specifically manifested in the improvement of human abilities and the extension of life cycle through investment in five aspects: healthcare, formal education, on-the-job training, and population mobility to adapt to employment opportunities. The improvement of labor quality formed by investment will contribute to economic growth for a long period of time. Schultz used human capital theory to explain the miracles of economic recovery in Germany and Japan after World War II, the Leontief puzzle, and the decline in the organic composition of capital, among other difficult issues in the economic field. However, Schultz only analyzed the role of human capital in economic growth at the macro level, without examining the relationship between human capital and individual income distribution at the micro level.

Gary Stanley Becker combines income distribution theory with human capital investment theory from a micro perspective, providing a more detailed discussion of various investments in human capital and the resulting returns, further improving the theory of human capital^[20]. Becker pointed out that "human capital is a specific type of capital formed through investment in human resources, which includes not only skills, abilities, and knowledge, but also factors such as health, lifespan, and time."^[20] Therefore, Becker believed that expenditures on education, on-the-job training, healthcare, labor migration, and collecting price and income information are all investments in human capital, which can improve labor productivity in the short and long term and promote economic development. From this, it can be seen that with the continuous deepening of theoretical research, human capital is no longer limited to knowledge, technology, and work abilities, but also includes individual health status and lifespan. Investment in human capital is no longer limited to education and job skills training, but also extends to personal nutrition supplementation and healthcare investment. Health, as a component of human capital, is gradually being recognized by scholars.

2.2.3 New Developments in Human Capital Theory

With the development of the new economic growth theory, some scholars have begun to introduce variables related to human capital into economic growth models to analyze the important role played by human capital in the process of economic growth. This marks a new stage in the application of human capital theory. The main representatives are Denison, Paul Romer, Robert Lucas, and M Scott and others. Among them, Denison proposed that the majority of economic development in the United States comes from technological advancements brought about by technology and education^[21]. Nelson, Romer, and Lucas' research suggests that human capital investment is an endogenous driving force for sustained regional economic growth, which can actively promote the formation and utilization efficiency of production factors^[22-23]. Some scholars divide China into four regions: western, inland, northeast, and coastal. Using empirical research methods, they analyze the contribution rates of material capital and human capital to economic growth in each region, and conclude that human capital plays an important role in economic development^[24].

2.2.4 Application of human capital theory in this article

The development of human capital theory has gradually formed a unified definition: human capital is a type of capital reflected in workers, manifested as their knowledge, skills, qualifications, experience, and proficiency, that is, their abilities and qualities; After the quality of human beings is established, human capital can be manifested as the total number of people and total working hours engaged in paid work in the labor market. From the perspective of human investment, human capital can be understood as the capital formed by human investment. In terms of monetary form, it manifests as various expenditures to enhance human capital, mainly including school education, on-the-job education, healthcare expenditures, and labor migration expenditures; Both individuals and society's investment in human capital will generate returns^[19]. Schultz's definition of human capital provides clear boundaries for future research in the field of human capital^[25]. This article cites Schultz's

definition of human capital and conducts research based on it. The definition of human capital can be summarized as follows: (1) Human capital is a production capacity embedded in workers, and this production capacity is based on the lives and health of workers [25]; (2) Human capital is ultimately reflected in the number of workers and the duration of labor supply; (3) In the process of economic development, the return on investment in human capital is higher than the rate of return on material capital. Human capital is a form of capital that corresponds to material capital and can bring permanent economic income, knowledge, and health to workers.

This article takes human capital theory as the theoretical basis for constructing an analytical framework, which is the core idea that runs through the entire text. For a long time, air pollution with PM_{2.5} as the main pollutant has caused serious damage to people's respiratory system and cardiovascular health, becoming an important cause of harm to people's health. Due to the fact that human capital is a type of capital reflected in workers, manifested in their abilities and skills, these abilities and skills are the production capacity of workers to create economic value and obtain income, and this production capacity is based on the life and health of workers. The life and health of individuals are not only important components of their human capital, but also carriers of the transformation of human capital into productivity. Therefore, this article builds an analytical framework based on human capital theory within the appropriate scope of its application. Based on the connotation and definition of human capital, this article analyzes the impact of air pollution on the health human capital and labor supply behavior of rural middle-aged and elderly people from the perspective of healthy human capital. Specifically, it is discussed in the following three parts.

(1) Measure the negative influence of air pollution on the health human capital of the rural mid-aged and elderly. The human capital theory holds that health is a component of human capital, and the loss of health means the loss of human capital. This section mainly focuses on the process and principles of PM_{2.5} fine particles acting on the human respiratory system and cardiovascular and cerebrovascular systems in clinical medicine. Within the framework of economic analysis, air pollution concentration is included in the research scope along with individual socio-economic characteristics. Focus on analyzing the correlation between air pollution concentration and the probability of middle-aged and elderly people in rural areas suffering from cardiovascular and respiratory diseases, while measuring the marginal effect of increasing air pollution concentration on improving the probability of elderly people in rural areas suffering from diseases.

(2) Mechanism analysis of the differential influence of ambient air pollution on the health of the rural mid-aged and elderly in different regions. The human capital theory emphasizes the importance of human capital investment in accumulating human capital, which is not limited to formal education, vocational training, and labor migration expenditures, but also includes investment in healthcare. In order to investigate whether the influence of ambient air pollution on rural mid-aged and elderly is influenced by regional economic conditions and medical service levels, this study will divide the sample into three equal parts according to local GDP and per capita hospital numbers, and explore the marginal effects of health loss caused by air contamination on rural middle-aged and elderly people under different regional economic and medical service levels.

(3) Analysis of the impact of health loss caused by air pollution on the labor supply behavior of the rural mid-aged and elderly. Based on the conclusion drawn in the previous section, air pollution has a negative impact on the health human capital of rural middle-aged and elderly people, and the degree of impact varies depending on the local economic situation and the level of medical and health services. This section further analyzes whether the health loss caused by air pollution will affect the various labor decisions of the rural mid-aged and elderly in agricultural and non-agricultural labor markets with different economic conditions, ages, and economic regions.

(4) Human capital includes the quantity and quality of labor supply provided by workers. This article mainly refers to the quantity of labor supply, using the working time of rural mid-aged and elderly people as a reference. Meanwhile, as mentioned earlier, air pollution will cause health loss, reduced physical fitness, and decreased labor capacity among rural mid-aged and elderly in rural areas, further affecting their labor supply time.

2.3 Health Needs Theory

In 1961, at the 13th meeting of the World Health Organization and the Pan American Health Commission, human health investment was first listed as an important component for promoting economic development. Mushkin included investment in health and education together in the category

of human capital investment. He pointed out that health has dual attributes of investment and consumption. As a consumer good, health not only improves consumer utility but also enhances consumer welfare; As an investment product, people purchase medical services to resist diseases^[26]. A healthy workforce helps to improve labor productivity and produce more products for society. Labor losses caused by diseases, such as death, disability, and physical weakness, will reduce labor time and production efficiency to varying degrees. And investment in healthcare can to some extent compensate for the loss of human capital caused by diseases.

Subsequently, some scholars further elaborated on the commodity attributes of health and pointed out that individuals acquire a certain amount of health capital through inheritance from their parents. However, healthy human capital will continue to decrease as individuals age, and the depreciation rate will continue to increase with age^[27]. Consumers compensate for the health loss caused by aging by purchasing medical services, so their demand for medical services is an extended demand for health needs and a demand for non-medical services themselves. In Becker's household production function, consumers' demand for medical services is included in the model. Within certain time and income budget constraints, consumers' consumption of health and other goods must satisfy the marginal utility ratio of the two goods, which is equal to the relative price ratio. The relative price here not only includes monetary prices, but also includes the time cost of consuming the goods, which are difficult to observe in the market and are called shadow prices. The shadow price of health affects people's demand for health.

The household production function only considers the utility function of consumers at a certain point in time, while the human life cycle is long, and the health status varies greatly at different stages of the life cycle, and the health depreciation rate is also different. The utility of health loss on individuals is not limited to the current period, but also has a certain lag^[27]. Grossman introduced the concepts of flow and stock based on the household production function^[28]. Grossman believed that individuals acquire their initial health capital stock through genetics, and as they age, their health capital decreases at a certain depreciation rate. When the health stock is zero, it means the end of life. Grossman constructed a demand model for health and health investment from the perspective of human capital, hence the Grossman model is also known as the human capital model of health demand^[28]. Grossman defines health as both a consumer good and an investment good. As a consumer good, health can free consumers from the pain of illness, provide physical and mental pleasure, and satisfy consumer utility; As an investment product, health is one of the elements of human capital, which can increase consumers' labor time in the labor market, increase their income, increase the number of other goods available for consumers to purchase in the market, and improve consumer utility^[28]. In order to offset the loss of health flow caused by aging, consumers can make health investments, that is, the time and other products invested by health demanders to maintain a healthy state, such as healthcare services, balanced diet, exercise, entertainment, and housing^[28]. Health capital investment is generated within the framework of household production function. In this analytical framework, health demand is negatively correlated with its shadow price, which is not only related to medical prices, but also to individual education level, gender, race, marital status, and environmental pollution. During the life cycle, the rate of decline in an individual's health condition will accelerate with age, and individuals with higher levels of education are often more efficient health producers, so shadow prices will rise with age. It is particularly important that under certain conditions, as shadow prices increase, health demand decreases, thereby increasing healthcare demand.

2.4 Work Leisure Model

Theodore W. Schultz pointed out that "human capital is reflected in people, manifested in their knowledge, skills, qualifications, experience, and proficiency, that is, in their abilities and qualities."^[19] Given the fixed quality of people, human capital can be regarded as the total number of people and total working hours engaged in paid work in the labor market. Therefore, it can be seen that the quality of human capital is ultimately manifested as the quality and quantity of labor of workers in the labor market. According to Grossman's health production function, an individual's health condition depends on the time they spend maintaining their health and the market products they invest in improving their health. Healthy investment behavior can increase individual health stock and enhance human capital; On the contrary, suffering from diseases will reduce an individual's health stock, lower the quality of human capital, and affect their performance in the labor market. This impact mechanism can be analyzed separately from the labor demand side and the supply side. For the labor demand side, due to the fact that workers with illnesses are not as physically and productive as healthy workers, their human capital is lower than that of healthy workers. Therefore, rational employers will reduce their

demand for labor services from workers with poor health conditions. For labor suppliers who suffer from illnesses that make it difficult for them to perform their original job tasks, workers with poor health will adjust their labor time supply or job positions according to their own situation. Since this article explores the impact of health loss caused by air contamination on labor supply from a micro individual perspective, it will further discuss the changes in labor supply caused by individual health loss from a theoretical perspective.

The analysis model of the influence of impact of chronic diseases on the labor supply of manual laborers is mainly based on the traditional work leisure model, assuming that individuals are rational "economic agents" who pursue utility maximization. Under the given conditions of personal time resources, they continuously adjust their leisure, market labor, and family labor time to achieve personal utility maximization. And changes in health status will affect their allocation of time resources. Usually, suffering from diseases will reduce their market labor supply time and increase their leisure time. When their health condition deteriorates too much to work, individuals will withdraw from the labor market.

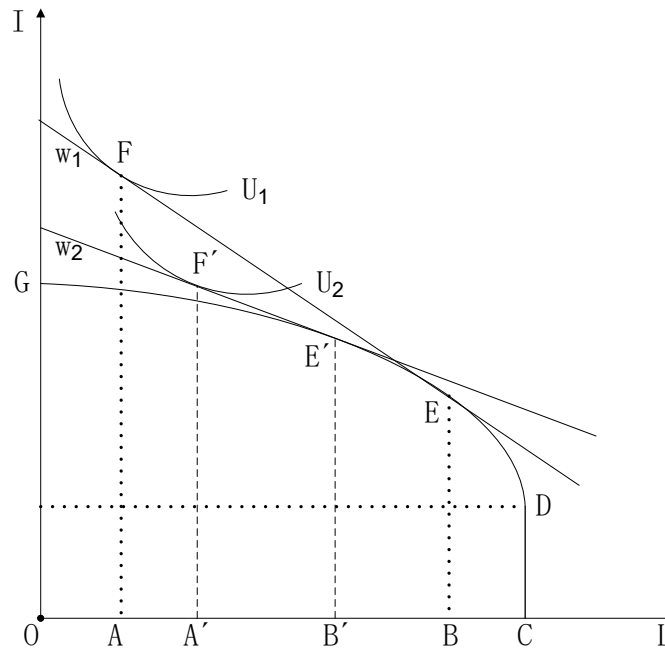


Figure 1: The influence of chronic diseases on the working hours of the rural mid-aged and elderly

As shown in Figure 1, the changes in leisure time, market labor, and household labor time of middle-aged and elderly rural laborers before and after suffering from diseases. The horizontal axis L represents labor time, and the vertical axis I represents income level. OC is the disposable time of an individual, assuming that the individual's initial income level is CD and the household production function curve is GC . Before the rural labor force fell ill, its indifference curve was U_1 , and the initial market wage rate was W_1 . Due to the fact that the allocation of time by workers is mainly based on the comparison of the utility of commodity consumption brought about by leisure, household labor, and the increase in market labor income. The labor price, also known as wages, represents the opportunity cost of leisure and household labor, therefore the wage level is an important factor affecting the market labor supply decisions of labor suppliers. When the market wage rate level is W_1 , in order to pursue utility maximization, this person's indifference utility curve U_1 is tangent to the market wage rate curve W_1 at point F , and OA allocates leisure time for them. W_1 is tangent to the household production function curve at point E , AB is the labor time allocated by individuals for market input, and BC is the household labor time, such as laundry, cooking, and other daily household activities.

3. Analysis framework

3.1 Impact mechanism of ambient air pollution on the health condition of rural mid-aged and elderly

Based on Croper's research results, this article introduces haze (PM2.5 fine particles) as the main

factor affecting individual health stock, and measures the impact of different PM_{2.5} concentrations on chronic respiratory diseases or cardiovascular and cerebrovascular diseases among the rural mid-aged and elderly^[19]. In general, air pollution mainly affects the respiratory system of the human body, causing chronic respiratory diseases such as cough, chronic bronchitis, and bronchial asthma. Fine particles with a diameter less than 2.5 microns (PM_{2.5}) can also carry toxic substances directly into the blood vessels of the human body through the alveoli, causing thickening of the vascular endothelium, vascular blockage, increased blood pressure, etc., increasing the possibility of triggering blood clots, and even causing heart diseases such as congestive heart failure and coronary artery disease. A large number of clinical studies have shown that long-term exposure to polluted air will not only promote the formation and progress of atherosclerosis, leading to damage to bronchial epithelial cells, inflammatory reactions in the lungs and respiratory system, but also lead to acute cardiovascular diseases, such as arrhythmia, heart failure, myocardial ischemia and sudden death, posing a huge threat to the life safety of patients. Respiratory and cardiovascular diseases have become the main diseases that harm national health, thereby affecting the accumulation of human capital for health. Based on the above analysis, this article believes that air pollution will exacerbate the health loss of middle-aged and elderly people in rural areas.

According to Grossman's theory of health needs, consumers can make health investments to offset the decline in health stock caused by aging, including purchasing healthcare services, nutrient intake, and improving work and living environments. The individual's investment in health is influenced by factors such as their health awareness and whether they have purchased medical insurance. Under the same level of air pollution damage, varying degrees of health investment will improve their health status and offset the health loss caused by air pollution. In general, the impact of polluted air on individual health is not short-term and requires a long-term accumulation process. The progression from acute dizziness and cough to chronic respiratory or cardiovascular diseases reduces an individual's health stock. Individuals with high health awareness attach great importance to their own health management, constantly monitor their health status, persist in exercise, and improve their immune system. Regular physical examinations allow for early detection and treatment of illnesses. When air pollution occurs, reduce outdoor time or wear masks to minimize direct exposure to polluted air. Individuals with weak health awareness may overlook the hazards of air pollution, fail to take necessary protective measures, and be exposed to polluted air for a long time. Lack of regular health check ups, failure to receive timely medical assistance when acute diseases are caused by air pollution, missing the best treatment time, and ultimately developing chronic diseases, greatly increasing the difficulty and cost of treatment. Meanwhile, medical insurance can compensate for the economic losses caused by disease risks among the rural mid-aged and elderly in rural areas, which to some extent affects their choice of medical services. Due to the fact that medical insurance can avoid or reduce the economic risks caused by the treatment of diseases among the rural mid-aged and elderly, those who participate in medical insurance tend to purchase higher quality medical services or increase the frequency of medical visits, which helps to control their condition in a timely manner and avoid disease deterioration. Based on the above discussion, this article believes that there are individual differences in the effect of ambient air pollution on the health condition of the rural mid-aged and elderly.

3.2 Impact mechanism of air pollution on labor supply for middle-aged and elderly people in rural areas

In general, chronic cardiovascular and respiratory diseases caused by air pollution can lead to dizziness, limb weakness, coughing, chest tightness, shortness of breath, and difficulty breathing. Although it is not a serious health shock, it does not require long-term bed rest. However, poor physical condition can affect the productivity and labor supply time of workers. Especially for manual laborers represented by farmers, healthy human capital is the main factor of production for manual laborers to earn income in the labor market. The deterioration of physical health will directly affect the productivity of manual laborers in the labor market, thereby affecting their income.

The decrease in labor productivity caused by health loss due to air pollution puts rural middle-aged and elderly people at a disadvantage in the labor market, resulting in a decrease in the remuneration per unit time. In order to adapt to the new wage level, individuals who fall ill will choose to increase their health investment and leisure time to restore their physical functions, while reducing their labor supply time. As the disease worsens and the family production function curve remains unchanged, individuals will continuously increase their leisure time and reduce their labor supply time until the labor supply time reaches zero, that is, they will exit the labor market. Based on the above analysis, this article believes that the health loss of rural middle-aged and elderly people caused by air pollution will affect

their labor supply behavior.

According to the analysis of the health work leisure model, in general, health shocks not only affect individuals' labor participation behavior, but also their labor supply time. The above analytical framework has certain applicability in analyzing the labor supply behavior of general rural residents. However, for the rural mid-aged and elderly with poor economic conditions, will this impact change? For the rural mid-aged and elderly with a certain economic foundation, when facing health shocks, they can choose to reduce labor supply time, increase leisure time, or directly withdraw from the labor market. For poor rural middle-aged and elderly people with poor economic conditions, in order to make up for the medical expenses caused by illness, their labor supply time is increased instead of reduced, in order to obtain more income to maintain medical expenses. Therefore, under the same health impact, the behavior of rural middle-aged and elderly people with different economic conditions in the labor market varies.

Due to the low educational level and lack of technical training of most rural residents, they mostly engage in high-intensity physical labor, and their health damage will seriously affect their labor supply efficiency and time. With the gradual acceleration of the transfer of rural young and middle-aged labor to urban areas and non-agricultural industries, the scarcity of rural labor in China will further intensify in the future^[29]. The particularity of agricultural labor and the difficulty of the working environment determine that health is an important production factor for farmers engaged in agriculture^[30], and the health status of farmers to some extent affects the supply of agricultural labor^[31].

At present, the basic economic system in rural areas of China still remains at the household contract responsibility system. Agricultural production is mainly based on households, with strong autonomy in agricultural labor arrangements and greater flexibility in labor supply. The input of agricultural production time is greatly affected by the health status of producers. Compared to other industries, farmers work in the fields and are exposed to polluted air for a longer period of time, making their bodies more susceptible to damage. From this, it can be seen that under the same air pollution conditions, agricultural workers exhibit stronger vulnerability and sensitivity compared to non-agricultural workers. Based on the above analysis, this article believes that the health loss caused by air pollution will lead to differences in the labor supply behavior of rural middle-aged and elderly people due to economic conditions, with agricultural labor being more affected than non-agricultural labor.

In studies evaluating the negative impact of air pollution on people's labor supply, some scholars have focused on the impact of air pollution on the production efficiency of workers in specific production sectors, such as agriculture, manufacturing, prison factories, and knowledge and technology intensive workers. Research has shown that air pollution significantly reduces the production efficiency of workers in different sectors^[32]. There are also literature dedicated to exploring whether there is a potential causal relationship between air pollution and labor supply losses, and some literature has shown that air quality is closely related to employee absenteeism and student absenteeism^[33]. The latest research findings provide new evidence for further exploring the impact of air pollution on labor supply time, such as Hanna, R., Oliva, P. (2015) using the closure of a large oil refinery in Mexico City as a "quasi natural experiment". Through the study, it was found that the closure of the refinery reduced local SO₂ emissions by 19.7%, thereby increasing the weekly working hours of local residents by 1.3 hours^[34]. Arag ó n et al. (2017) discovered the mechanism by which air pollution reduces people's labor supply time by increasing the burden of household care^[35]. Zhang Z et al. (2018) constructed a theoretical model to explain the underlying mechanism of air pollution reducing labor supply time from a macro perspective^[36].

4. Research conclusions

This article focuses on the theoretical analysis of the impact of air pollution on the health loss and labor supply of middle-aged and elderly people in rural areas. Based on human capital theory, Grossman's health needs theory, and the work leisure model, this study analyzes whether air pollution increases the probability of cardiovascular and chronic respiratory diseases among middle-aged and elderly rural residents within the framework of economics, providing a theoretical basis for further analysis of the health and labor supply losses caused by air pollution on rural residents. Firstly, it is discussed that health is an important component of human capital. Healthy human capital can improve production efficiency, increase labor time, and is an endogenous driving force for long-term stable economic development. According to Grossman's health needs theory, environmental pollution can

have a negative impact on individual health, and individuals' investment in their own health can effectively offset the health loss caused by environmental pollution, maintain their physical health, and promote the accumulation of human capital for health. The similarities and differences in economic and social conditions among individuals can lead to significant differences in their investment measures and efforts towards their own health. Therefore, under the same air pollution environment, rural middle-aged and elderly people with different income levels, medical security levels, and health awareness may have different reactions and lead to health differences.

Secondly, using the work leisure model, analyze whether the health loss caused by air pollution has an impact and mechanism on the labor supply behavior decisions of middle-aged and elderly people in rural areas. The logical chain is that air pollution increases the risk of chronic diseases among middle-aged and elderly people in rural areas, causing damage to their health. To restore their health level, pollution victims can only choose to increase their health investment time, that is, increase their rest time and reduce their labor supply time. Rational rural middle-aged and elderly people will constantly adjust the allocation of leisure time, market labor, and household labor to achieve maximum utility.

Starting from the health of rural residents, a theoretical analysis framework of "air pollution - farmers' health level - rural labor supply" is constructed to clarify the inherent logical relationship and mechanism of air pollution, health loss, and labor supply. Applying clinical medicine to research on rural labor supply and expanding the application of human capital theory and health demand theory in this area. Currently, most research on the relationship between ambient air contamination and labor supply is focused on urban areas, with a lack of research on rural areas. This article will extend the study of tentacles to rural areas, construct an analytical framework based on human capital theory at the micro individual level, investigate the loss of health human capital of rural residents exposed to air pollution, and explore the agricultural labor supply losses caused by health problems. The use of Grossman's health needs theory to analyze the impact and mechanism of air contamination on the health human capital of the rural mid-aged and elderly enriches the theoretical research on rural labor supply.

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