

Original Research Article

Environmental tax, self-mitigation cost and wage inequality between skilled and unskilled labor in developing countries

ABSTRACT: The paper incorporates both environmental tax and self-mitigation cost of labor into a three-sector general equilibrium model. In the basic model, the pollution affects labor health and drives parts of labor out of the factor market, and find that results of a larger environmental tax on wage inequality rely on the elasticity of substitution between labor and dirty input in the unskilled sector, an increase in the self-mitigation cost of skilled and unskilled labor narrows down wage inequality. The robustness of the basic model on the impact of a greater environmental tax and the self-mitigation cost of unskilled labor is substantiated by the extended model that incorporates the bad externality of pollution on agricultural production; however, the impact of a rise in the self-mitigation cost of skilled labor on wage inequality in the extended model is different, depending on the elasticity of pollution on agricultural production.

KEYWORDS: Environmental tax, self-mitigation cost of labor, wage inequality.

1. Introduction

The rising skilled-unskilled wage inequality in developing countries has provoked the great interest of many theoretical economists. In the literature, studies in the determination of wage inequality generally focus on international factor mobility and trade (Marjit and Kar, 2005; Chaudhuri and Yabuuchi, 2007; Beladi et al, 2008; Chaudhuri, 2008; Wang et al, 2009; Chaudhuri and Banerjee, 2010; Anwar and Sun, 2012). Until recently, one line of research has paid attention to domestic factors to explain the wage inequality in developing countries. In these studies, a variety of mechanisms are proposed to model the impact of a change in a domestic factor on the wage inequality such as public infrastructure provision (Pi and Zhou, 2012), domestic

remittances (Li and Zhou, 2013), taxation on labor income (Anwar and Sun, 2015), privatization (Chao et al, 2016), capital market distortion (Pi and Chen, 2016), skill-biased technical change (Behar, 2016), pollution control (Pi and Zhang, 2017).

In this study, we examine the issue of wage inequality but offer a different mechanism. The paper incorporates both environmental tax and self-mitigation cost of labor (the cost to prevent or cure the bad effect generated by pollution) into a general equilibrium model. The justifications for accommodating these two domestic factors are twofold. First, the industrialization of the developing world is creating unsustainable industrial pollution and developing countries, in general, are facing a severe environmental problem. The environmental tax is a common preservation policy to address this problem and has a substantial cost advantage over other instruments such as pollution control. Its effects are also explored by many scholars from different perspectives (Williams, 2002; Daitoh, 2008; Yanase, 2010; Daitoh and Omote, 2011; Kuo et al, 2017). However, existing literature on the environmental tax neglects to consider the issue of the wage gap, and thus fails to analyze the effect of the environmental tax on the skilled-unskilled wage inequality. Second, the fact that increasingly serious pollution poses a threat to labor health has become more pronounced¹. People have to invest more money and time to prevent or cure the bad effect generated by pollution. Previous studies on the bad externality of pollution in developing countries focus on the bad externality on agricultural production (Kondoh and Yabuuchi, 2012; Li and Wu, 2016; Pi and Zhang, 2017) and pay little attention to its effect on labor health. Thus, the role of the private self-mitigation effort in determining wage gap has largely ignored.

In order to fill the current research gap and address the issues mentioned above, this paper establishes three-sector general equilibrium models to investigate the impacts of increased environmental tax and self-mitigation cost of skilled and unskilled labor on the skilled-unskilled wage inequality. The basic model, which assumes the pollution only affects labor health, shows that a larger environmental tax rate brings to a reduction of the wage gap if the elasticity of substitution between labor

¹ Take the air pollution for example. The WHO data shows that there is now little or no escape from the plague of poisoned air; people in 98% of cities in developing countries with more than 100,000 inhabitants are breathing air with pollution levels that exceed WHO minimum safety guidelines. Moreover, the problem is rapidly worsening as most Asian and African cities burgeon without planning controls, as car numbers multiply and as industry and transport are allowed to pollute the air more or less unhindered. More detail see http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/

and dirty input in the unskilled sector is large enough; however, the wage gap will be expanded if the elasticity of substitution is small enough. Suppose that the self-mitigation cost of skilled and unskilled labor is raised, the wage inequality will be narrowed down. The robustness of the basic model on the impact of a greater environmental tax and the self-mitigation cost of unskilled labor is substantiated by the extended model that incorporates the bad externality of pollution on agricultural production; however, the impact of a rise in the self-mitigation cost of skilled labor on wage inequality is different, depending on the elasticity of pollution on agricultural production.

The rest of the paper is organized as follows: we establish a basic model with three sectors in Section 2 and investigate the effects of a change in the environmental tax and self-mitigation cost of skilled and unskilled labor on wage inequality. In Section 3, we incorporate the bad externality of pollution on agricultural production. Concluding remarks are made in Section 4.

2. The basic model

Consider a small open economy that composes of three sectors: an urban skilled sector, an urban unskilled sector and an agricultural sector. The urban skilled sector (sector 1) uses skilled labor L_{S1} and capital K_1 to produce an exportable good X_1 , while the unskilled sector (sector 2) uses unskilled labor L_{U2} , capital K_2 and dirty input D to produce an import-competing good X_2 ². The agricultural sector (sector 3) employs unskilled labor L_{U3} and land T to produce an agricultural good X_3 . In addition, skilled labor, dirty input and land are specific to the skilled sector, unskilled sector and agricultural sector, respectively. Capital moves freely between skilled and unskilled sector; however, unskilled labor moves imperfectly between unskilled sector and agricultural sector due to the rigid downward wage in the unskilled sector. Here we discuss the difference between these skilled and unskilled sector. Skilled sector mainly refers to high-end manufacturing which need expertise and skilled labor in production, while traditional manufacturing, like plastic material, chemical, could be classified as unskilled sector. In the setting, labor is heterogeneous and capital could mobile

² Here, the model treats the dirty input as an input in the production of the unskilled sector. Similar setting could refer to Yohe (1979), Yu and Ingene (1982), Beladi and Frasca (1999), Daitoh (2008), Pi and Zhang (2017), and Kuo et al. (2017).

between sectors. Such assumptions are strongly backed by the fact that high-end and traditional manufacturing still coexist by using different ability employees but having access to similar source of capital. Since skilled labor is the shortage in the developing countries generally, assume urban unemployment only exists among unskilled labor and the movement of unskilled labor from agricultural sector to unskilled sector satisfies the Harris-Todaro equilibrium condition (Harris and Todaro, 1970). The production functions are $X_1 = F^1(L_{S1}, K_1)$, $X_2 = F^2(L_{U2}, K_2, D)$, and $X_3 = F^3(L_{U3}, T)$, where the three functions satisfy the neoclassical properties (i.e., strict quasi-concavity and linear homogeneity). For simplicity, assume that the dirty input market does not exist. To control externality of the dirty input, the government levies a corrective tax ρ of per unit of the dirty input. All the goods and factor markets, except the labor market, are perfectly competitive. The cost minimization conditions for three production sectors are described as:

$$p_1 = a_{S1}w_S + a_{K1}r \quad (1)$$

$$p_2 = a_{U2}\bar{w}_U + a_{K2}r + a_{D2}\rho \quad (2)$$

$$1 = a_{U3}w_U + a_{T3}\tau$$

(3)

where p_1 and p_2 are good prices of skilled sector and unskilled sector relative to that of agricultural sector, respectively, and p_1 and p_2 are assumed to be given and constant in a small open economy. a_{ij} ($i = S, U, K, D, T; j = 1, 2, 3$) represents that the factor i used in producing one unit of good in the j th sector. w_S is the wage rate of skilled labor in the skilled sector. \bar{w}_U is the wage rate of unskilled labor in the urban unskilled sector, which is downward rigid due to the protection of labor unions. w_U is the wage rate of unskilled labor in the agricultural sector, which is fully elastic. r is the interest rates of capital. ρ is the amount of tax per capita, which represents the price of the dirty input. τ indicates the rent of land.

Use $\lambda = L_{UU}/a_{U2}X_2$ to denote the unemployment rate of unskilled labor in the urban region. The Harris-Todaro unskilled labor market equilibrium condition is given by

$$w_U(1 + \lambda) = \bar{w}_U$$

(4)

Among three sectors, only unskilled sector generates pollution³. And assume the pollution is generated during the production process of unskilled sector and δ expresses the units of pollution generated by one unit of production of the unskilled sector, and $0 < \delta < 1$ ⁴. Thus, pollution $E = \delta X_2$. As previous mentioned, pollution discussed in this paper affects skilled and unskilled labor health, either causing labor to spend time sick or by reducing its productivity. Such kinds of impacts shift some labor away from productive activities, leading to a reduction in the amount of labor available for production. Following Williams(2002), assume the pollution affects labor health, resulting in either reducing the amount or productivity of total labor. More specific, the pollution E drops $t_S E$ and $t_U E$ amounts of skilled and unskilled labor away skilled and unskilled labor market, respectively. t_i ($i = S, U$) is the per capital effect of pollution on i type labor, and $t_i > 0$. t_i ($i = S, U$) determines the extent of the effect of pollution on i type labor and also indicates the private cost to avoid the bad effect of pollution. In the following, we call t_i is the self-mitigation cost of i type labor. A greater value of t_i means a larger effect of pollution on health and labor must spend a larger cost to keep health. The market-clearing conditions yield:

$$a_{S1}X_1 = L_S - t_S E \quad (5)$$

$$(1 + \lambda)a_{U2}X_2 + a_{U3}X_3 = L_U - t_U E$$

(6)

$$a_{K1}X_1 + a_{K2}X_2 = K \quad (7)$$

$$a_{T3}X_3 = T \quad (8)$$

³ The reason is that the unskilled sector, like steel, printing, plastic material, chemical, is usually an emission intensive sector in developing countries and uses dirty inputs to production.

⁴ Concerning pollution in the theoretical literature, there are two methods associated with the generation of pollution broadly. The first regards factor inputs generate pollution in the production process, and pollution equals the dirty input (Yu and Ingene, 1982; Beladi and Frasca, 1999; Daitoh, 2008; Pi and Zhang, 2017; Kuo et al, 2017). The second approach views the generation of pollution as by-products during the production process (Tsakiris et al, 2008; Tawada and Sun, 2010; Li and Zhou, 2015). Since the two approaches arrives similar results and the latter approach is less complicated than the former one, we adopt the latter approach in this paper.

where L_S, L_U, K, T are the endowment of skilled labor, unskilled labor, capital and land, respectively. Noting that urban unemployment is $L_{UU} = \lambda a_{U2} X_2$, the first item in equation (4) $(1 + \lambda) a_{U2} X_2$ expresses the total unskilled labor in the urban region.

In accordance with the denotation of skilled-unskilled wage inequality in Chaudhuri and Yabuuchi (2007), Beladi et al. (2008), Li and Xu (2016) and Pi and Zhang (2017), the paper also uses the skilled labor wage and the average wage of unskilled labor, as well as their relative change to address the issue concerning the skilled-unskilled wage gap. Combining with equation (4) and (6), the average wage of unskilled labor is w_U .⁵

So far, the theoretical model has been established. Eight endogenous variables, $w_S, w_U, r, \tau, \lambda, X_1, X_2$ and X_3 , are determined by equation (1)–(8), t_s, t_U and ρ are policy variables. Other variables are exogenous. Now, under the framework, we will investigate the impacts of an increase in environmental tax on the wage inequality, which can be summarized by Proposition 1.

Proposition 1 Suppose the share of exited skilled labor is not large. A larger environmental tax rate brings a reduction of the wage gap if the elasticity of substitution between labor and dirty input in the unskilled sector is large enough; however, the wage gap will be expanded if the elasticity of substitution is small enough.

Proof. The system could decompose into two sub-systems. Equation (1), (2), (5), (7), constitute a sub-system which determines w_S, r, X_1 , and X_2 . Totally differentiating equation (1), (2), (5), (7), we obtain these results:

$$\frac{\hat{w}_S}{\hat{\rho}} = \frac{\theta_{K1} \theta_{D2}}{\theta_{S1} \theta_{K2}} > 0, \quad \frac{\hat{r}}{\hat{\rho}} = -\frac{\theta_{D2}}{\theta_{K2}} < 0,$$

$$\frac{\hat{X}_1}{\hat{\rho}} = \frac{\lambda_s \theta_{D2} \Psi_1 - \lambda_{K2} \Psi_2}{\Delta_1}$$

and

$$\frac{\hat{X}_2}{\hat{\rho}} = \frac{\lambda_{K1} \Psi_2 - \lambda_{S1} \theta_{D2} \Psi_1}{\Delta_1}$$

⁵ Here, we only consider the wage of labor in the market and do not include the dropped labor.

where “ \wedge ” represents the rate of change (e.g., $\hat{w}_S = dw_S/w_S$), $\Delta_1 = \lambda_{K1}\lambda_{ts} - \lambda_{K2}\lambda_{S1}$,

$$\Psi_1 = -\left[\lambda_{K1}\sigma_{SK}^1 + \lambda_{K2}(\theta_{D2}\sigma_{KD}^2 + \theta_{K2}\sigma_{KD}^2 + \theta_{U2}\sigma_{UK}^2)\right]/\theta_{K2} < 0,$$

$\Psi_2 = \lambda_{S1}\theta_{D2}\theta_{K1}\sigma_{SK}^1/(\theta_{K2}\theta_{S1}) > 0$. θ_{ij} ($i=S,U,K,D,T; j=1,2,3$) is the distributive share of factor i in the j th sector (e.g. $\theta_{S1} = a_{S1}w_S/p_1$), λ_{ij} is the allocated share of factor i in the j th sector (e.g. $\lambda_{U3} = a_{U3}X_3/L_U$), $\lambda_{ts} = t_S E/L_S$ is share of exited skilled labor, σ_{ij}^h ($i,j=S,U,K,D,T; h=1,2,3$) is the elasticity of substitution between factors i and j in the h th sector.

The sign of Δ_1 is ambiguous. Here, we impose an inequality $\lambda_{S1}/\lambda_{K1} > \lambda_{ts}/\lambda_{K2}$. Note that λ_{ts} is the share of exited skilled labor caused by the unskilled sector, which is be deemed as the skilled labor “employed” by the unskilled sector. And in this perspective, we call $\lambda_{ts}/\lambda_{K2}$ as the per capita capital of the skilled labor in unskilled sector. $\lambda_{S1}/\lambda_{K1}$ expresses the per capita capital of the skilled labor in skilled sector. And the inequality means the per capita capital of the skilled labor in skilled sector is larger than the per capita capital of the skilled labor in the unskilled sector. Consider the economic reality, the value of λ_{ts} is relatively small and this inequality is easily satisfied in the real economy. Thus, we have $\Delta_1 < 0$, $\hat{X}_1/\hat{\rho} > 0$ and $\hat{X}_2/\hat{\rho} < 0$.

Totally differentiating equation(3),(4),(6)and (8),

$$\begin{aligned} & \left\{(1+\lambda)\lambda_{U2}\theta_{D2}(\sigma_{UD}^2 - \sigma_{UK}^2) + (\lambda_{K1}\Psi_2 - \theta_{D2}\lambda_{S1}\Psi_1)[(1+\lambda)\lambda_{U2} + \lambda_{tu}]/\Delta_1\right\}\hat{\rho} \\ & - \lambda_{K1}\lambda_{ts}[(1+\lambda)\lambda_{U2} + \lambda_{tu}]/\Delta_1\hat{t}_S + \lambda_{tu}\hat{t}_U = [(1+\lambda)\lambda_{U2} + \sigma_{UT}^3\lambda_{U3}/\theta_{T3}]\hat{w}_U \end{aligned} \quad (9)$$

where $\lambda_{tu} = t_U E/L_U$ is share of exited unskilled labor. Substitution relevant results into (9), we have

$$\frac{\hat{w}_U}{\hat{\rho}} = \frac{\theta_{T3}\left\{(1+\lambda)\lambda_{U2}\theta_{D2}(\sigma_{UD}^2 - \sigma_{UK}^2) + (\lambda_{K1}\Psi_2 - \theta_{D2}\lambda_{S1}\Psi_1)[(1+\lambda)\lambda_{U2} + \lambda_{tu}]/\Delta_1\right\}}{(1+\lambda)\lambda_{U2} + \sigma_{UT}^3\lambda_{U3}/\theta_{T3}}$$

and

$$\frac{\hat{w}_S - \hat{w}_U}{\hat{\rho}} = \frac{\theta_{K1}\theta_{D2}}{\theta_{S1}\theta_{K2}} - \frac{\theta_{T3}\left\{(1+\lambda)\lambda_{U2}\theta_{D2}(\sigma_{UD}^2 - \sigma_{UK}^2) + (\lambda_{K1}\Psi_2 - \theta_{D2}\lambda_{S1}\Psi_1)[(1+\lambda)\lambda_{U2} + \lambda_{tu}]/\Delta_1\right\}}{(1+\lambda)\lambda_{U2} + \sigma_{UT}^3\lambda_{U3}/\theta_{T3}}$$

Suppose that σ_{UD}^{2*} is the solution of $(\hat{w}_S - \hat{w}_U)/\hat{\rho} = 0$. If $\sigma_{UD}^2 > \sigma_{UD}^{2*}$, then

$(\hat{w}_S - \hat{w}_U)/\hat{\rho} < 0$; and if $\sigma_{UD}^2 < \sigma_{UD}^{2*}$, $(\hat{w}_S - \hat{w}_U)/\hat{\rho} > 0$. ■

The economic explanation of Proposition 1 is as follows. An increase in the environmental tax drops the dirty input, which lowers the employment of capital and unskilled labor in the unskilled sector. The output of unskilled sector and pollution reduces. The supply of skilled labor raises due to the improvement of environment, which generates a negative on its wage. While the inflow of capital increases the marginal productivity and has a positive effect on its wage. Consider the fact the share of exited skilled labor is not large, the latter impact is dominant and skilled wage increases finally. Regarding the impact of a reduction of dirty input on employment of unskilled labor in the unskilled sector, less input of dirty decreases the demand of unskilled labor; however, a higher price of pollution will stimulate the substitution dirty input with unskilled labor that raises the demand of unskilled labor. If the elasticity of substitution between unskilled labor and dirty input is relatively small, which implies the substitution is relatively hard, and the decrease of demand for unskilled labor will be dominant. More unskilled labor will be located in the agricultural sector and reduces the status quo wage of unskilled labor. Thus, wage gap expands. If the substitution is large enough and the demand for unskilled labor and the status quo wage of unskilled labor will increase. A greater of environmental tax will exert a relatively larger positive impact on unskilled wage than that of skilled labor and wage gap will be narrowed down.

Next consider the impacts of a change in the self-mitigation cost of skilled and unskilled labor. From the established model, a change in the self-mitigation cost of skilled and unskilled labor does not affect the skilled wage. Its impact on unskilled wage is obtained by equation(9),

$$\frac{\hat{w}_U}{\hat{t}_S} = -\frac{\lambda_u \theta_{T3} \lambda_{K1} [(1 + \lambda) \lambda_{U2} + \lambda_u]}{[(1 + \lambda) \lambda_{U2} \theta_{T3} + \lambda_{U3} \sigma_{UT}^3] \Delta_1} > 0$$

$$\frac{\hat{w}_U}{\hat{t}_U} = \frac{\lambda_u \theta_{T3}}{(1 + \lambda) \lambda_{U2} \theta_{T3} + \lambda_{U3} \sigma_{UT}^3} > 0$$

where $\lambda_u = t_U E / L_U$ is share of exited unskilled labor. Thus, $(\hat{w}_S - \hat{w}_U) / \hat{t}_S < 0$ and $(\hat{w}_S - \hat{w}_U) / \hat{t}_U < 0$. From the above analyses, use Proposition 2 to state the effect exerted by a increase in the self-mitigation cost of skilled and unskilled labor on the wage inequality.

Proposition 2 If the self-mitigation cost of skilled and unskilled labor is increased, the wage inequality will be narrowed down.

Under the model, a change in the self-mitigation cost of skilled and unskilled labor will not affect the skilled wage and we focus their impacts on unskilled wage. It is easy to obtain that an increase in the self-mitigation cost of unskilled labor will raise the unskilled wage due to less supply of unskilled labor in the market. Here, we need to explain why a change of the self-mitigation cost of skilled labor increases the unskilled wage. An increase in the self-mitigation cost of skilled labor will make less skilled labor available and reduces the marginal marginal productivity of capital employed in the skilled sector. Capital moves from the skilled sector to unskilled sector and reduces interest rate. Since the unskilled wage rate in the unskilled sector is constant, this sector uses more capital and unskilled labor to expand its output until the interest rate equals to its previous equilibrium value. Less unskilled labor will be employed in the agricultural sector and unskilled wage raises.

3. Extension: pollution affects agricultural production

In this section, we will consider the pollution not only affects labor health but also exerts a negative impact on agricultural production. Pollution, which imposes damage to the agricultural environment through agents such as air and water, is the bad public good. Since the pollution affects the whole sector, we incorporate the pollution into the agricultural production function as “creation of atmosphere” type in Meade’s terminology (Meade,1952). The technology of agricultural sector exhibits constant returns to scale only in the primary factors(labor and land in the model) in production. Thus, the production function of agricultural sector is expressed as $X_3 = g(E)F^3(L_{U3}, T)$, where $E = \delta X_2$ is the pollution, $g(E)$ expresses the impact of pollution on the agricultural sector. And $g(E)$ has the properties that $g'(E) < 0$, $g''(E) > 0$, $g(0) = 1$, and $0 < g(E) < 1$. In addition, the negative impact of pollution on the agricultural output can be captured by the elasticity:

$$\varepsilon = (dg/g)/(dE/E) < 0$$

Thus, equation(3) will be changed to:

$$g(E) = a_{U3}w_U + a_{T3}\tau \quad (10)$$

where a_{i3} ($i = U, T$) represents the factor i used in producing one unit of goods (without pollution effect) in the agricultural sector (e.g., $a_{U3} = L_{U3}/F^3$). And equation(6) and (8) will be changed to

$$(1 + \lambda)a_{U2}X_2 + a_{U3}F^3 = L_U - t_U E$$

$$(11)$$

$$a_{T3}F^3 = T \quad (12)$$

So far, the extended model with pollution affects labor health and agricultural production has been constructed. Eight equations (i.e., (1), (2), (4), (5),(7), (10),(11), and (12)) determine eight endogenous variables, $w_S, w_U, r, \tau, \lambda, X_1, X_2$ and X_3 , are determined, t_S, t_U and ρ are policy variables. Equation(1),(2),(5),(7), constitute a sub-system which determines $w_S, r, X_1,$ and X_2 . Totally differentiating equation (1), (2),(5),(7), we obtain these results are same with these in the section 2. Totally differentiating equation(4),(10),(11),and (12),and substituting relevant results in the section 2,

$$\begin{aligned} & [(1 + \lambda)\lambda_{U2} + \lambda_{uu} + \lambda_{U3}\varepsilon\sigma_{UT}^3/\theta_{T3}][\hat{\rho}(\lambda_{K1}\Psi_2 - \theta_{D2}\Psi_1\lambda_{S1})/\Delta_1 - \lambda_{ts}\lambda_{K1}\hat{t}_S/\Delta_1] \\ & + (1 + \lambda)\lambda_{U2}\theta_{D2}(\sigma_{UD}^2 - \sigma_{UK}^2)\hat{\rho} + \lambda_{uu}\hat{t}_U = [(1 + \lambda)\lambda_{U2} + \lambda_{U3}\sigma_{UT}^3/\theta_{T3}]\hat{w}_U \end{aligned} \quad (13)$$

From the equation(13),

$$\frac{\hat{w}_U}{\hat{\rho}} = \frac{(1 + \lambda)\lambda_{U2}\theta_{D2}(\sigma_{UD}^2 - \sigma_{UK}^2) + (\lambda_{K1}\Psi_2 - \theta_{D2}\lambda_{S1}\Psi_1)[(1 + \lambda)\lambda_{U2} + \lambda_{uu} + \lambda_{U2}\varepsilon\sigma_{UT}^3/\theta_{T3}]/\Delta_1}{(1 + \lambda)\lambda_{U2} + \sigma_{UT}^3\lambda_{U3}/\theta_{T3}}$$

and

$$\begin{aligned} \frac{\hat{w}_S - \hat{w}_U}{\hat{\rho}} = & \frac{\theta_{K1}\theta_{D2}}{\theta_{S1}\theta_{K2}} \frac{(1 + \lambda)\lambda_{U2}\theta_{D2}(\sigma_{UD}^2 - \sigma_{UK}^2) + (\lambda_{K1}\Psi_2 - \theta_{D2}\lambda_{S1}\Psi_1)[(1 + \lambda)\lambda_{U2} + \lambda_{uu} + \lambda_{U2}\varepsilon\sigma_{UT}^3/\theta_{T3}]/\Delta_1}{(1 + \lambda)\lambda_{U2} + \sigma_{UT}^3\lambda_{U3}/\theta_{T3}} \end{aligned}$$

When the elasticity of pollution on agricultural production is large enough (i.e., $\varepsilon > -\theta_{T3}[(1 + \lambda)\lambda_{U2} + \lambda_{uu}]/(\lambda_{U2}\sigma_{UT}^3)$) (small enough, i.e. $\varepsilon < -\theta_{T3}[(1 + \lambda)\lambda_{U2} + \lambda_{uu}]/(\lambda_{U2}\sigma_{UT}^3)$), and suppose that $\sigma_{UD}^{2\&} (\sigma_{UD}^{2\&\&})$ is the solution of $(\hat{w}_S - \hat{w}_U)/\hat{\rho} = 0$. If $\sigma_{UD}^2 > \sigma_{UD}^{2\&}$ ($\sigma_{UD}^2 > \sigma_{UD}^{2\&\&}$), then $(\hat{w}_S - \hat{w}_U)/\hat{\rho} < 0$; and if $\sigma_{UD}^2 < \sigma_{UD}^{2\&}$ ($\sigma_{UD}^2 < \sigma_{UD}^{2\&\&}$), $(\hat{w}_S - \hat{w}_U)/\hat{\rho} > 0$. Thus, when incorporating the externality of pollution on the

agricultural production, the wage inequality depends on the substitution of unskilled labor and dirty inputs in the unskilled sector, regardless of the elasticity of pollution on agricultural production. Note that the elasticity of pollution on agricultural production affects the crucial value of the substitution of unskilled labor and dirty inputs, and $\sigma_{UD}^{2\&}$ is larger than $\sigma_{UD}^{2\&\&}$.

From the equation(13),

$$\frac{\hat{w}_U}{\hat{t}_S} = \frac{-\lambda_{K1}\lambda_{ts}[(1+\lambda)\lambda_{U2} + \lambda_{uu} + \varepsilon\lambda_{U3}\sigma_{UT}^3/\theta_{T3}]/\Delta_1}{(1+\lambda)\lambda_{U2} + \sigma_{UT}^3\lambda_{U3}/\theta_{T3}}$$

and

$$\frac{\hat{w}_U}{\hat{t}_U} = \frac{\lambda_{uu}}{(1+\lambda)\lambda_{U2} + \sigma_{UT}^3\lambda_{U3}/\theta_{T3}} > 0$$

Since $\hat{w}_S/\hat{t}_S = 0$ and $\hat{w}_S/\hat{t}_U = 0$, $(\hat{w}_S - \hat{w}_U)/\hat{t}_U < 0$ and

$$\frac{\hat{w}_S - \hat{w}_U}{\hat{t}_S} = \frac{\lambda_{K1}\lambda_{ts}[(1+\lambda)\lambda_{U2} + \lambda_{uu} + \varepsilon\lambda_{U3}\sigma_{UT}^3/\theta_{T3}]/\Delta_1}{(1+\lambda)\lambda_{U2} + \sigma_{UT}^3\lambda_{U3}/\theta_{T3}}$$

If the elasticity of pollution on agricultural production is large enough (i.e., $\varepsilon > -\theta_{T3}[(1+\lambda)\lambda_{U2} + \lambda_{uu}]/(\lambda_{U2}\sigma_{UT}^3)$) (small enough, i.e. $\varepsilon < -\theta_{T3}[(1+\lambda)\lambda_{U2} + \lambda_{uu}]/(\lambda_{U2}\sigma_{UT}^3)$), $(\hat{w}_S - \hat{w}_U)/\hat{t}_S < 0$ ($(\hat{w}_S - \hat{w}_U)/\hat{t}_S > 0$).

Summarizing the above results,

Proposition 3 When pollution affects labor health as well as agricultural production,
(1) A greater environmental tax rate will be reduced the wage gap if the elasticity of substitution between labor and dirty input in the unskilled sector is large enough; however, the wage gap will be expanded if the elasticity of substitution is small enough. Moreover, the the elasticity of pollution on agricultural production affects the crucial value of the elasticity of substitution.
(2) If the self-mitigation cost of unskilled labor increases, the wage inequality will be narrowed down ambiguously; however, the impact of a rise in the self-mitigation cost of skilled labor on wage inequality depends on the elasticity of pollution on agricultural production.

The economic explanation of the first part of Proposition 3 is similar as that in the Proposition 1, except the effect of the elasticity of pollution on agricultural production

on the crucial value of the elasticity of substitution between labor and dirty input. A greater environmental tax will reduce the output of unskilled sector and pollution. If the elasticity of pollution on agricultural production is large enough, the positive effect exerted by reduced pollution as well as unskilled wage is relatively small. Thus, the crucial value of the elasticity of substitution between labor and dirty input is relatively large. If the elasticity of pollution on agricultural production is small enough, the positive effect exerted by reduced pollution as well as unskilled wage is relatively large. Thus, the crucial value of the elasticity of substitution between labor and dirty input is relatively small.

The result of a rise in the self-mitigation cost of unskilled labor on wage gap is identical with that in the Proposition 2. However, different with the previous result that an increase in the self-mitigation cost of skilled labor reduces wage gap unambiguously, when considering the pollution affects the agricultural production, its effect depends on the elasticity of pollution on agricultural production. A change in the self-mitigation cost of skilled will not affect the skilled wage and here focus its impact on the unskilled wage. From the explanation of the Proposition 2, an increase in the self-mitigation cost of skilled labor will expand the demand for unskilled labor and output of unskilled sector. Expansion of unskilled sector will generate two contrasting effects on unskilled wage. More demand for unskilled labor and more pollution emitted as a result of an expansion. The former raises the unskilled wage, while the latter reduces the unskilled wage. If the elasticity of pollution on agricultural production is large enough (small enough), which implies a change of pollution affects the production and unskilled wage of agricultural sector in a relatively small (large) magnitude, the former (latter) effect is dominant, and a rise in the self-mitigation cost of skilled labor reduces (raises) wage gap.

4. Concluding remarks

Recently, theoretical scholars have tried to address the growing skilled-unskilled wage inequality from the domestic factors such as public infrastructure, domestic remittances, factor market distortion, instead of trade and international factors mobility. However, considering the severe pollution and its increasing impact on the labor health, environmental tax and self-mitigation cost are also crucial reasons for the wage gap in developing countries. The government and private have made their efforts to reduce the

bad externalities of pollution. Therefore, it is worth investigating the impacts of a greater of environmental tax and self-mitigation cost on wage gap.

This paper establishes two three-sector general equilibrium models to investigate the impacts of an increase in the environmental tax and self-mitigation cost of skilled and unskilled labor on wage inequality. In the basic theoretical model, we consider the pollution affects the labor and find that results of a larger environmental tax on wage inequality rely on the elasticity of substitution between labor and dirty input in the unskilled sector, an increase in the self-mitigation cost of skilled and unskilled labor narrows down wage inequality. The robustness of the basic model on the impact of a greater environmental tax and the self-mitigation cost of unskilled labor is substantiated by the extended model that incorporates the bad externality of pollution on agricultural production; however, the impact of a rise in the self-mitigation cost of skilled labor on wage inequality is different, depending on the elasticity of pollution on agricultural production.

Here, we point out several possible extensions for future research. Firstly, pollution may affect the utility of labor. In the paper focuses on the externality of pollution on the supply-side of economy instead of demand-side. In the future, we can take pollution on the demand-side of economy and investigate the optimal amount of tax rate. Secondly, the current studies and this paper focus on industrial pollution instead of agricultural pollution. Currently, developing countries also experience severe agricultural pollution due to overuse of chemical materials. Thirdly, this paper only considers the exogenously determined wage rate of unskilled sector. Other cases, such as endogenous minimized wage of unskilled sector, with practical significance in developing countries can also be taken into consideration.

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