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Employment effects of environmental taxes and subsidies

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Abstract

This paper presents a new perspective on environmental tax reform. Assuming that households prefer clean goods over dirty ones, we demonstrate that implementing taxes on dirty goods alongside subsidies for clean goods can lead to an increase in employment. This rise in employment is driven by enhanced purchasing power resulting from a greater decline in prices compared to wages, motivating households to work more. As for the environmental dividend, consumption of polluting goods tends to decrease. However, an unintended feedback effect emerges due to the increased purchasing power resulting from the positive impact of subsidies on employment and the consumption of non-polluting goods. If the two types of goods are not perfect substitutes, this rise in purchasing power can lead to greater consumption of polluting goods, thereby limiting improvements in environmental quality. Hence, while subsidy policies can be more acceptable due to the employment benefit, their efficiency is still questionable.

Keywords: Environmental tax, subsidy, clean goods, dirty goods, employment.

JEL classification D62 D63 H23 Q52

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Highlights

- The employment effects of environmental taxes and subsidies are investigated
- A general equilibrium model with imperfect labor markets is considered
- Workers are heterogeneous and derive utility from consuming clean and dirty goods
- The policy leads to improvements in both employment and environmental quality
- However, increase in purchasing power may hinder environmental quality improvement

1 Introduction

It is usually argued that implementing pollution taxes can enhance environmental quality. Indeed, Bureau et al. (2019) demonstrate that despite the use of various environmental policy tools such as technical standards for vehicles and buildings, subsidies for clean technologies and renewable energies, and energy efficiency programs, these measures are still less effective than carbon tax. They argue that without the implementation of carbon taxes, European countries are unlikely to achieve their CO_2 emissions reduction targets by 2030. Environmental taxation is the best instrument because it enables any emissions reduction target to be achieved at the lowest cost, and leaves private agents - households and businesses - the choice of how and how much to reduce emissions (Bureau et al., 2019).

Despite their efficiency, taxes are unpopular among voters ; and hence often politically infeasible (Sælen and Kallbekken, 2011). They are perceived by numerous households as an extra tax primarily driven by financial needs rather than climate policy objectives Bureau et al. (2019). This point of view is supported by the study of Douenne and Fabre (2020b), which found that the rising revenues from the carbon tax were predominantly allocated to the budget instead of being redistributed to households. Environmental taxation is also considered unfair, particularly for the least affluent households and those with limited options, such as in transportation (Bureau et al., 2019).

This paper examines whether an environmental tax combined with subsidies for consumption goods can enhance environmental quality and promote employment, thereby mitigating the trade-off between efficiency and equity. By providing subsidies for clean goods as assumed in our proposed policy, we implicitly assume that these grants will fully compensate for the adverse effects of polluting taxes on real wage and promote employment. Indeed, studying the effect of an increase in the pollution tax on employment, Bovenberg and De Mooij (1994) found that the negative effects of the environmental tax on employment is due to a decline in the real after-tax wage, eroding the incentives to supply labor. They found that this drop in the real after-tax wage comes about because the lower tax on labor income does not fully compensate workers for the adverse effect of the pollution levy on their real after-tax wage. Parry (1998) also found that subsidies that reduce the relative price of consumption goods increase the real household wage, and produce an efficiency gain by encouraging labor supply.

Thus, employing an analytical framework similar to that of Aubert and Chiroleu-Assouline (2019), [1] we demonstrate that, under the assumption that preferences of households for clean goods outweigh their preferences for dirty goods, the combination of taxes on dirty goods with subsidies for clean goods leads to an increase in employment. This rise in employment stems from the increase in purchasing power due to a greater decline in prices compared to wages that provides households with incentives to work more. This finding is plausible, as it indicates that the higher the proportion of clean goods in a household's consumption basket, the more effectively he is compensated for the adverse effects of increased pollution taxes on their real wage. As for the environmental dividend, consumption of polluting goods tends to decrease. However, an unintended feedback effect emerges due to the increased purchasing power resulting from the positive impact of subsidies on employment and the consumption of non-polluting goods. If the two types of goods are not perfect substitutes, this rise in purchasing power can lead to greater consumption of polluting goods, thereby limiting improvements in environmental quality. Hence, while subsidy policies can be more acceptable and help attain the employment benefit, their efficiency is still questionable.

This paper makes three significant contributions to the literature. First, unlike previous studies, our research adds nuance to the effects of environmental policies by emphasizing the importance of household preferences in the success of some environmental policies. Second, on a theoretical level, our study provides a crucial contribution by offering a theoretical foundation to empirical researches (Verma and Imelda, 2023; Imelda, 2018), as this issue has rarely been addressed theoretically. A similar study has been undertaken by Fullerton and Wolverton (2005), but, in their tax-subsidy combination, taxes are applied to all labor and capital income rather to dirty goods as implied by the deposit-refund

[1] Within this model, workers exhibit heterogeneity, labor markets are imperfect, and there are externalities arising from the consumption of polluting goods.

system to which our policy is similar.[2] Furthermore, whereas Fullerton and Wolverton (2005), wish to establish an equivalence between their reform and the standard Pigouvian tax, the present paper explores the employment effects of an environmental policy which aims at encouraging clean good consumption and discouraging dirty good consumption. Finally, the study slightly diverges from the double dividend theory (Goulder, 1995), as the tax revenues from polluting goods are reinvested in environmental causes rather than explicitly used for labor market reforms.[3]

Our focus on subsidies for the consumption of clean goods aligns with various studies, indicating that earmarking tax revenue for environmental purposes significantly enhances public support (Douenne and Fabre, 2020a). As highlighted by Deroubaix and Lévèque (2006), people often struggle to understand why the proceeds from an environmental tax reform should be used to address unemployment. Furthermore, Bovenberg (1995) shown that shifting the tax burden from low-income to middle-income earners can negatively impact their effort and incentives to acquire skills. Concerning the policy acceptance, Douenne and Fabre (2020a) found that the preferred revenue recycling options of French people are investments in the energy transition. They also shown that the second preferred mechanism for revenue recycling is a reduction in the Value Added Tax (VAT) rate.[4] As a complement to ecological taxation, subsidies are also justified to assist households that are financially constrained and lack access to credit in changing their equipment (Bureau et al., 2019). In this approach, equipment that consumes relatively little power, or goods that are relatively non-polluting, could benefit from a subsidy, while energy-intensive and/or highly polluting products could be taxed in proportion to their energy efficiency or degree of harmfulness (Callonnec and Sannié, 2009). This policy was introduced in

[2] A deposit-refund system combines a tax on product consumption with a rebate when the product or its packaging is returned for recycling. Deposit-refunds are used for beverage containers, lead-acid batteries, motor oil, tires, various hazardous materials, electronics, and more (Walls, 2011).

[3] It seems that positive effects of the reduction of employers' social security contribution or the reduction of the cost of labor are only obtained if demand for low-skilled labor is very sensitive to the cost of that labor, yet several studies have indicated that companies are more interested in the quality of labor than in its cost (Marx, 2001).

[4] The main rationales for this support are the benefits to one's purchasing power and the perceived distributive effects. Indeed, as the VAT is known to be a regressive tax, people may perceive it fair to compensate an increase in the regressive carbon tax with a decrease in the VAT (Douenne and Fabre, 2020a).

France in 2008 and remains in effect. Under this system, less polluting cars can benefit from a subsidy of up to $1,000$ euros, while the most polluting ones are subject to an additional tax of $2,600$ euros (d'Haultfoeuille et al., 2014). Furthermore, Greiner (2018) suggests that to encourage the use of clean goods and shape individual preferences towards them, significant subsidies should be provided for these environmentally friendly goods.

The article is structured as follows : section 2 revisits relevant studies on the employment effects of environmental policies. Following this section, we present, in section 3, the model used in our analysis. In section 4, we present and interpret the results of our analysis. The final section summarizes our findings and discusses their implications for the implementation of environmental policy.

2 Literature

The effects of environmental policies on employment and aggregate economic activity have also been at the heart of earlier papers. Modelling the effects of an environmental tax with a reduction in income taxes, Ekins et al. (2011), show that, at a European Union aggregate level, the environmental tax reform would generally create a positive change in real incomes for all socioeconomic groups and hence encourage employment. Hafstead and Williams III (2018), find that imposing a pollution tax causes substantial reductions in employment in the regulated (polluting) industry, but this is offset by increased employment in the unregulated (nonpolluting) sector. Determining the effects of environmental taxes on employment in a sample of 94 countries with different levels of development, both within and outside the OECD, Domguia et al. (2022), find that environmental tax promotes the emergence of new sectors of activity and therefore has a positive and significant effect on total employment. In a theoretically model, Zhong et al. (2021), find that the employment of high-skilled labor will grow along with the intensification of environmental regulation while that of the low-skilled labor will decline first and then rebound, showcasing a U-shaped curve. These results from their theoretical analysis are confirmed by their empirical research based on the provincial dynamic panel data from 2004 to 2018 in China. The analysis of Wang and Ouattara (2020), is based on a differentiated

Cournot duopoly in which the wages of employees are negotiated with a centralized trade union. They show that an increase in the environmental tax decreases employment with the presence of the trade union. Those studies on African countries, namely Degirmenci and Aydin (2021), also shows that environmental taxes increased environmental degradation and unemployment in Cameroon, environmental degradation in the Ivory Coast, environmental degradation and employment in Mali, environmental restoration in South Africa and employment in Uganda.

Other studies are related to environmental policies that combine both taxes and recycling measures. Carraro et al. (1996) show that using carbon tax revenues to reduce employers' social security contributions may provide an "employment double dividend" only in the short-run, and that these short-run effects can increase and last for a larger number of periods when the union's bargaining power is lower or when the labor market is more competitive. Using progressive labor taxes reduction as a recycling option, Aubert and Chiroleu-Assouline (2019), find that an environmental tax reform, associated with a progressive labor-tax, limit the ongoing climate change, and boost employment and welfare, without widening inequalities. Maxim (2020), also find that a reduction in labor tax is the most potent green tax reform policy measure to entail "triple dividend" defined as the reduction of carbon dioxide emissions (first dividend), increase in gross domestic product (second dividend), and higher employment (third dividend). As for Rengs et al. (2020), subsidy for greener products performs very well in emission reduction but face significant adverse economic side-effects, such as a considerably higher unemployment or a lower GDP, thus achieving a reduction in total emissions partly through economic decline. The work of Verma and Imelda (2023) on subsidizing liquefied petroleum gas in Indonesia also revealed that the increase in labor supply resulted from improved household health and time savings. However, in Verma and Imelda's study, the policy included a quantity restriction as the regions benefiting from the subsidies were no longer supplied with kerosene.[5]

[5]The liquid petroleum gas program in Indonesia is an environmental policy that combines a price subsidy with quantity restrictions, as areas benefiting from the liquefied gas subsidy are no longer supplied with kerosene (Verma and Imelda, 2023; Pertamina et al., 2012). Kerosene withdrawal was done only in areas in which the conversion packages were distributed completely. The withdrawal was accomplished

Despite this substantial literature on the employment effects of various environmental policies, the employment effects of an environmental policy that combines taxes on dirty goods with subsidies for clean goods, as assumed in our study, have received relatively less attention. Thus, in the present study, there will be no quantity restrictions. Households' access to polluting goods will be restricted through the use of taxes. This will allow for an assessment of the success of such a policy based on preferences.

3 The model

We consider an economy composed of firms, government, and households.

3.1 Households

There are two types of households, differentiated by their earning abilities, which are reflected in their respective wages. A mass of $N_H = N$ represents the high-skilled group with higher wages, while the remaining mass of $N_L = 1$ represents the low-skilled group with lower wages. We assume endogenous labor supply for high-skilled workers, while low-skilled workers supply one unit of labor. Similar to Keuschnigg and Ribi (2009), we also assume that only low-skilled workers face unemployment. For this purpose, we use, for the determination of employment of low-skilled workers, a matching process in the spirit of Pissarides (2000).

Households ignore the adverse effect of their consumption of polluting goods. They are risk-neutral and have identical tastes for clean and dirty goods, assumed to be imperfect substitutes. To account for the potential regressivity of green tax reform, we employ a specific utility function represented by the Stone-Geary preferences type, as in Aubert and Chiroleu-Assouline (2019) and Klenert and Mattauch (2016). Hence, the period felicity function of each household is given by,

$$Q_i = q(C_i, D_i) = C_i^{1-\sigma}(D_i - \bar{D})^{\sigma} \quad 0 < \sigma < 1. \tag{1}$$

by gradually cutting the agents' allocation and kerosene supply.

where C_i and D_i are respectively the amounts of clean and dirty goods consumed by the household, and $\bar{D}$ ($\bar{D} > 0$) is the minimum-consumption requirement for dirty good. The use of terminology "dirty" refers to good whose consumption is harmful for environment while, "clean" commodity is to be the good causing little pollution during their use. σ is the elasticity of the utility function for dirty goods. This parameter quantifies the responsiveness of the agent's utility to changes in the level of dirty goods consumption. Consequently, we can define the term $1 - \sigma$ as the elasticity of the utility function with respect to changes in the level of clean goods consumption.

Denoting I_i as the overall income of a household, each household will be faced with the following budget constraint:

$$(1 - s) C_i + (1 + t_D) D_i = I_i \quad \text{with} \quad s < t_D \tag{2}$$

where t_D represents the tax on each unit of consumption of dirty goods and s the subsidy to each unit of clean good consumed. With the assumption of weakly separability between leisure and consumption utility, the maximization of the utility function (1) with respect to the budget equation (2), yields respectively the following demands for clean and dirty goods resulting from the first order conditions (See appendix A),

$$C_i^* = \frac{1 - \sigma}{1 - s} \left[I_i - (1 + t_D) \bar{D} \right], \tag{3}$$

$$D_i^* = \frac{\sigma}{1 + t_D} \left[I_i - (1 + t_D) \bar{D} \right] + \bar{D}. \tag{4}$$

After using equations (3) and (4) together with equation (1), we also obtain the indirect utility (Q_i^*) for each household, and the marginal price of consumption (P_Q):

$$Q_i^* = \frac{I_i - (1 + t_D) \bar{D}}{P_Q}, \tag{5}$$

$$P_Q = \left[\frac{1 - s}{1 - \sigma} \right]^{1 - \sigma} \left[\frac{1 + t_D}{\sigma} \right]^{\sigma}. \tag{6}$$

Income of high-skilled workers is determined by their labor income, $(1 - t_H)Hw_H$ where t_H is the tax rate on their labor income Hw_H, w_H their wage rate and H is the amount of labor they supply. As for low-skilled workers, they earn $(1 - t_L)\, w_L$, when employed and, B, when unemployed. w_L represents the wage rate prevailing on the labor market of low-skilled workers, while t_L represents the tax rate on their labor income. Since we are considering a static model, we consider that the ex ante probability of being unemployed, u, of low-skilled workers equals their ex post rate of unemployment. Taking account of the income of each category of households, we derive, V_L and V_H, representing respectively indirect utility for low-skilled and high-skilled worker. These utilities are represented as,

$$V_L = u\, V_L^U + (1 - u)\, V_L^E - \zeta(D_{tot}) \quad \text{and} \tag{7}$$

$$V_H = \max_H \left[Q_H^*((1 - t_H)\, H\, w_H) - \Phi(H) \right] - \zeta(D_{tot}). \tag{8}$$

In these equations, we have assumed that the effect of the environmental externality, denoted as D_{tot}, on the utility function is linear. Thus, $\zeta(D_{tot})$ represents the disutility resulting from the degradation of the quality of environment. The terms $V_L^E = Q_L^*(1 - t_L)w_L$ and $V_L^U = Q_L^*(B) + Z$ respectively represent the indirect utility for a low-skilled worker when he is employed or unemployed. Z represents a money equivalent value of leisure or home production, and $\Phi(H) = \frac{H^{1+\frac{1}{\eta_H}}}{1+\frac{1}{\eta_H}}$ represents the cost of effort of a high-skilled worker. Thus, following the combination of equations (8) and (5), the optimal labor supply for a high-skilled worker follows (see appendix B),

$$H^* = \left[\frac{(1 - t_H)\, w_H}{P_Q} \right]^{\eta_H}, \tag{9}$$

from which we see that the high-skilled's labor supply increases as his real wage, $\frac{w_H}{P_Q}$, increases.

3.2 Firms

We consider one sector of production represented by a mass 1 of firms that produce output using labor services from high-skilled workers and low-skilled workers as inputs. Their technology of production is given by

$$y = f(l,h) = l^{\alpha}\, h^{1-\alpha} \tag{10}$$

where $f(l,h)$ represents a homogeneous Cobb-Douglas function displaying constant return to scale for l, representing demand for low-skilled labor, and $h = NH$, representing demand for high-skilled labor. The price of the good produced is fixed and normalized to unity. This good can serve for both public consumption and private consumption of clean and dirty commodities.

As previously assumed, only low-skilled workers experience unemployment in this model. This unemployment is attributed to matching frictions, and to determine the employment of low-skilled workers, we adopt a matching process similar to the approach presented in Pissarides (2000). Firms are a mass of 1. In addition to wages provided to low-skilled workers, they also incur hiring costs, denoted as c, when posting and maintaining a vacancy until it is successfully filled by a low-skilled worker. The probability for a firm looking for a low-skilled worker to find one is given by the matching function $\frac{\mathcal{M}}{v} < 1$, where $\mathcal{M}$ is defined as $\mathcal{M}(v,1)$. 1 represents the mass of job searchers, and v is the number of vacant jobs. The matching function exhibits constant returns to scale, with positive first partial derivatives and negative second derivatives. The tightness ratio of labor market is defined as $\theta = \frac{v}{1}$. Thus, an increasing θ raises the chance of a worker to locate a job and reduces the probability with which a firm is able to fill vacancies. Based on this definition, the probability that a firm looking for a low-skilled worker finds one equals $q(\theta) = \frac{\mathcal{M}}{v} = \mathcal{M}(1, 1/\theta)$. We assume that vacant jobs get filled according to a related Poisson process. As for firms, the probability with which an unemployed worker also finds a job is $\frac{\mathcal{M}}{1} < 1$. Making use of $\theta = \frac{v}{1}$, this probability can be expressed as, $\mathcal{M} = \mathcal{M}(\frac{v}{1}, 1) = \mathcal{M}(\theta, 1) = \theta\, \mathcal{M}(1, 1/\theta) = \theta\, q(\theta)$. Since a low-skilled worker's *ex ante* probability of being employed is equal to the *ex post* employment rate, we have $\theta q(\theta) = l$ where l represents the employment rate. With the unemployment rate defined as $u = 1 - l$, we express the Beveridge curve equation as,

$$u \ = \ 1 \ - \ \theta \, q(\theta). \tag{11}$$

After defining these different elements, firm's profit maximization can be expressed as, $\pi(y) \ = \ \max_{l,h} \left[l^{\alpha} \, h^{1-\alpha} - l \, w_L - w_H \, h - \ l \, \frac{c}{q(\theta)} \right]$, from which we derive, in appendix C, the following equations :

$$p_L \ = \ w_L \ + \ \frac{c}{q(\theta)} \quad \text{and} \tag{12}$$

$$p_H \ = \ w_H, \tag{13}$$

with $p_L \ = \ \alpha \ l^{\alpha-1} \ k^{1-\alpha}$ and $p_H \ = \ (1 \ - \ \alpha) \ l^{\alpha} \ k^{-\alpha}$ representing the productivity of low-skilled workers and high-skilled workers, respectively. By examining these various equations, it becomes evident that only the labor market for high-skilled workers is competitive, because their productivity equals the wage rate prevailing in their labor market.

Once a suitable low-skilled worker is found for a vacant job, a job rent appears and is shared between low-skilled workers and firms following a decentralized Nash bargain process,

$$w_L \ = \ argmax \left\{ \left(\, V_L^E \ - \ V_L^U \, \right)^{\beta} \, \left(\, p_L \ - \ w_L \, \right)^{1 \, - \, \beta} \right\} \quad \text{with} \quad 0 \ < \ \beta \ < \ 1. \tag{14}$$

where β is the bargaining power of low-skilled workers. $V_L^E - V_L^U$ represents the matching surplus for each low-skilled worker who is initially unemployed, while firms matching surplus is given by the difference between their profit, when they fill a vacancy, and the hiring cost, when they remain with a vacant job, $(p_L - w_L - c) - (0 - c) = p_L - w_L$. Using the first-order conditions from the maximization of Nash product, we find that the wage mark-up, $w_L - w_R$, can be expressed as,

$$w_L \ - \ w_R \ = \ \frac{\beta}{1 \ - \ \beta} \, \frac{c}{q(\theta)} \ = \ \frac{\beta}{1 \ - \ \beta} (p_L \ - \ w_L), \tag{15}$$

where we demonstrate in appendix D that the reservation wage w_R can be expressed as, $w_R = \frac{B + P_Q Z}{1 - t_L}$. This reservation wage tends to increase as the marginal price of consumption, P_Q, increases. Through the rearrangement of equation (15), we can derive the wage rate for low-skilled workers as a function of their reservation wage and bargaining power,

$$w_L = w_R + \beta (p_L - w_R). \tag{16}$$

This equation illustrates that low-skilled workers receive the reservation wage w_R and a fraction β of the surplus they create when accepting jobs. Moreover, it indicates that the labor market for low-skilled workers becomes more competitive as their bargaining power approaches 1. Conversely, when the bargaining power of firms approaches 1, low-skilled workers only receive the reservation wage.

3.3 Government

To address the negative impact of dirty goods on the environment and improve overall environmental quality, the government implements a green tax on the consumption of these goods. Alongside the proceeds from labor taxes, the revenue from the green tax are used by the government to subsidize the consumption of clean goods, provide a public good G, and fixed unemployment benefit B. This leads to a balanced-budget condition,

$$G + (1 - l)\, B + s\, (C_L + N\, C_H) = l\, w_L\, t_L + N\, H\, w_H\, t_H + t_D\, (D_L + N\, D_H)\,. \tag{17}$$

When solving the market equilibrium condition, $y = N\, C_H + C_L + N\, D_H + D_L + G$ for $(N\, C_H + C_L)$, and substituting the result in (17), we find that

$$(1 - s)\, G + (1 - l)\, B + s\, y = l\, w_L\, t_L + N\, H\, w_H\, t_H + (t_D + s)\, (D_L + N\, D_H) \tag{18}$$

We assume that only the tax rate, t_D, and the subsidy rate, s, vary and the other taxes and public good provision are kept constant ($dt_H = dt_L = dG = 0$). Both tax on dirty good and subsidy for clean good are Laffer-efficient and change by the same amount, as implied by assumption 1:

Assumption 1. $dt_D = ds$: The increase in the tax rate on polluting goods is associated with a corresponding increase in the subsidy rate for non-polluting goods.

Defining marginal revenue from tax on dirty goods as G_{t_D} $(= \frac{dG}{d_{t_D}})$ and marginal revenue from subsidy to clean goods as G_s $(= \frac{dG}{ds})$; Laffer-efficient condition for s and t_D implies that : $G_{t_D} > 0$ and $G_s < 0$. Thus, differentiating government budget constraint and solving the output for the change in the subsidy, we obtain after some rearrangement that :

$$\frac{G_{t_D}}{G_s} = -1, \tag{19}$$

where

$$G_{t_D} = \frac{1}{1-s}\left[\begin{array}{c} D_{tot} + lw_L t_L \left(\frac{\partial\, w_L}{w_L\, \partial\, t_D} + \frac{\partial\, l}{l\, \partial\, t_D}\right) + NHw_H t_H \left(\frac{\partial\, w_H}{w_H \partial\, t_D} + \frac{\partial\, H}{H\, \partial\, t_D}\right) \\ + B\, \frac{\partial\, l}{\partial\, t_D} + t_D\, \frac{\sigma}{1+t_D}\, \left(\frac{\partial\, I_{tot}}{\partial\, t_D} - \frac{I_{tot}}{1+t_D}\right) - s\left(p_L \frac{\partial\, l}{\partial t_D} + N\, p_h\, \frac{\partial\, H}{\partial\, t_D}\right) \end{array}\right]$$

and

$$G_s = \frac{G}{1-s} + \frac{1}{1-s}\left[\begin{array}{c} D_{tot} + lw_L t_L \left(\frac{\partial\, w_L}{w_L\, \partial\, s} + \frac{\partial\, l}{l\, \partial\, s}\right) + NHw_H t_H \left(\frac{\partial\, w_H}{w_H\, \partial\, s} + \frac{\partial\, H}{H\, \partial s}\right) \\ + B\, \frac{\partial\, l}{\partial s} + s \frac{\sigma}{1+t_D} \frac{\partial\, I_{tot}}{\partial\, s} - y - s\left(p_L\, \frac{\partial\, l}{\partial\, s} + N\, p_h\, \frac{\partial\, H}{\partial\, s}\right) \end{array}\right].$$

This means that all the revenues raised by the tax on dirty goods are returned to the households as subsidies for clean goods consumption.

4 Results and Interpretations

In this section, we draw on the usual definition of double dividend of Bovenberg (1999), and thus investigates how environmental policy in our setting influences quality of environment, employment and welfare. To investigate these impacts, the model is log-linearized. Therefore, we use the tilde ($\sim$) notation to represent relative changes in initial values, except for $\tilde{t}_L$ and $\tilde{t}_H$, which are defined as $\tilde{t}_L = \frac{t_L}{1-t_L}$ and $\tilde{t}_H = \frac{t_H}{1-t_H}$, respectively.

4.1 The economic dividend

Following Bovenberg (1999), Koskela and Schöb (2002) and Krass et al. (2013), economic dividend, in this section, refers to the impact of the policy on employment. This impact concerns both low and high skilled workers. Demands for high and low skilled labor are similar. Given the technology of production $y = l^{\alpha}\, h^{1-\alpha}$ as defined in (10), productivities of high-skilled and low-skilled workers equal, respectively, $p_H h = (1 - \alpha)y$ and $p_L l = \alpha y$. Linearizing these equations, we find changes in demands for high-skilled and low-skilled labor as follows:

$$\tilde{h}^d = \tilde{y} - \tilde{p}_h, \tag{20}$$

$$\tilde{l}^d = \tilde{y} - \tilde{p}_L. \tag{21}$$

These changes are positively related to change in output ($\tilde{y}$), and negatively related to change in labor cost for each type of household ($\tilde{p}_h$, $\tilde{p}_L$). Labor supply of high-skilled worker is derived following the same procedure as demand for labor. Linearizing equation (9) and using budget neutral condition (19), we find change in labor supply for high-skilled worker as follows,

$$\tilde{h}^s = \eta_H \left[\tilde{p}_H - \left[\frac{\sigma}{1 + t_D} - \frac{1 - \sigma}{1 - s}\right] dt_D\right]. \tag{22}$$

Since there is no friction on high-skilled labor market, employment level on this market results from equilibrium conditions that requires labor supply to equal labor demand. Thus, combining equations (20) and (22), we obtain employment change for high-skilled workers as follows :

$$\tilde{h}^* = \frac{\eta_H}{1 + \eta_H}\, \tilde{y}^* - \frac{\eta_H}{1 + \eta_H} \left[\frac{\sigma}{1 + t_D} - \frac{1 - \sigma}{1 - s}\right] dt_D. \tag{23}$$

Now, let's focus on the low-skilled labor market. Employment on this segment of market is determined by three equations : the first pertains to the Beveridge curve (11), the second corresponds to the job-creation equation (12), and the third represents the solution of the

Nash product (16). Using log-linearized forms of these equations, we show, in appendix E, that change in employment of low-skilled workers follows,

$$\tilde{l} = \eta_L \, \tilde{p}_L - \eta_R \frac{P_Q \, Z}{B + P_Q \, Z} \left[\frac{\sigma}{1 + t_D} - \frac{1 - \sigma}{1 - s}\right] dt_D, \tag{24}$$

where $\eta_L = \frac{1-\xi}{\xi} \frac{p_L}{p_L - w_R}$ represents elasticity of low-skilled employment with respect to the change in productivity ($\tilde{p}_L$) and $\eta_R = \eta_L \frac{w_R}{p_L}$ represents elasticity of low-skilled employment with respect to change in reservation wage $\tilde{w}_R$. Substituting equation (21) in equation (24), the change in employment of low-skilled workers becomes,

$$\tilde{l}^* = \frac{\eta_L}{1 + \eta_L} \tilde{y}^* - \frac{\eta_R}{1 + \eta_L} \frac{P_Q \, Z}{B + P_Q \, Z} \left[\frac{\sigma}{1 + t_D} - \frac{1 - \sigma}{1 - s}\right] dt_D. \tag{25}$$

Thus, using the relation $\tilde{y} = \alpha \, \tilde{l} + (1 - \alpha) \, \tilde{h}$ to eliminate $\tilde{y}$ in both equations (25) and (23), we obtain, after solving for h and l,

$$\tilde{l}^* = - \frac{\left[(1 + \alpha \, \eta_H) \, \eta_R \, \tilde{w}_R + (1 - \alpha) \, \eta_L \, \eta_H \tilde{P}_Q\right]}{1 + (1 - \alpha) \, \eta_L + \alpha \, \eta_H} \tag{26}$$

$$\tilde{h}^* = - \frac{\left[\alpha \, \eta_R \, \eta_H \, \tilde{w}_R + (1 + (1 - \alpha) \, \eta_L) \, \eta_H \, \tilde{P}_Q\right]}{1 + (1 - \alpha) \, \eta_L + \alpha \, \eta_H} \tag{27}$$

where $\tilde{P}_Q = \left[\frac{\sigma}{1+t_D} - \frac{1-\sigma}{1-s}\right] dt_D$ and $\tilde{w}_R = \frac{P_Q \, Z}{B+P_Q \, Z} \left[\frac{\sigma}{1+t_D} - \frac{1-\sigma}{1-s}\right] dt_D = \frac{P_Q \, Z}{B + P_Q \, Z} \, \tilde{P}_Q$.

These results give us an opportunity to assess the impact of policy on employment of both high-skilled and low-skilled workers. One evident observation is that the changes in the employment of both low-skilled and high-skilled workers are influenced by variations in the reservation wage, $\tilde{w}_R$, and the consumption price index, $\tilde{P}_Q$. This aligns with the suggestions of previous studies that the influence of environmental policy on employment stems from its effect on the purchasing power of households, which subsequently impacts their incentives to work (Bovenberg and De Mooij, 1994). Although changes in employment are influenced by variations in the reservation wage and consumer price index, the impact of the policy on these variables is ambiguous and dependent on the preference parameters. Specifically, the policy results in a negative variation in the reservation wage ($\tilde{w}_R < 0$) and consumer price index ($\tilde{P}_Q < 0$) when households prefer clean goods over dirty goods. Conversely, when the preferences of households for dirty goods outweigh their preferences for clean goods, we observe an increase in the reservation wage and consumer price index. Let's make the following assumption for the rest of our analysis,

Assumption 2. Households' preferences for clean goods outweigh their preferences for dirty goods: $1 - \sigma > \sigma$.

Under this assumption, an increase in tax on dirty goods coupled with a uniform rise in subsidy for clean goods results in a decline in the reservation wage and consumer price index. As both the reservation wage and consumer price index are negatively correlated with changes in employment, this leads to an increase in the employment of both low-skilled and high-skilled workers. In summary, we assert that,

Proposition 1. *Under the assumption that households' preferences for clean goods outweigh their preferences for dirty goods, implementing an environmental tax policy, where the generated revenues are reinvested as subsidies for the consumption of clean goods, leads to an increase in employment for both low-skilled and high-skilled workers.*

Proof. See appendix F ∎

This outcome can be attributed to the impact of the policy on reducing both the marginal price of consumption and the reservation wage when households prefer clean goods over dirty goods. The decrease in the marginal price of consumption highers the purchasing power of high-skilled workers and encourages them to supply more labor, as implied by equation (9). Additionally, we observe that wages decrease less than prices, meaning, $\tilde{P}_Q < \tilde{w}_R < 0$. For low-skilled workers, this leads to an increase in purchasing power, thus augmenting their incentives to work. Consequently, both high-skilled and low-skilled workers benefit from our proposed scheme in terms of employment.

4.2 The environmental dividend

This dividend represents the so-called "first dividend" and characterizes the impact of the reform on the quality of the environment. As the consumption of dirty good is harmful for environment, environmental dividend occurs when the policy contributes to decrease demand for polluting goods. In appendix G, we demonstrate that the change in demand for dirty goods follows,

$$\tilde{D}_{tot} = \frac{\left[\begin{array}{r} -\left(2\,\tau_2\,\tilde{t}_L + 2\,\tau_3\,\frac{q(\theta)}{1-q(\theta)}\right)\tilde{l} - 2\,\tau_4\,\tilde{t}_H\,\tilde{h} - 2\,\tau_2\,\tilde{t}_L\,\tilde{w}_L - 2\,\tau_4\,\tilde{t}_H\,\tilde{w}_H \\ +\,(\tau-\tau_1)\,ds\,+\,2\,s\left(\tau_2\,\frac{\tilde{t}_L}{t_L}\,+\,\frac{\tau_6}{q(\theta)}\right)\tilde{l}\,+\,2\,s\,\tau_4\,\frac{\tilde{t}_H}{t_H}\,\tilde{h} \end{array}\right]}{\tau_5\,+\,s\,\tau_1} \tag{28}$$

$\tau = \frac{C_{tot}}{I_{tot}}$ represents the share of the budget allocated to the consumption of clean goods in the total income

$\tau_1 = \frac{D_{tot}}{I_{tot}}$ represents the share of the budget allocated to the consumption of dirty goods in the total income

$\tau_2 = \frac{I^E_{LT}}{I_{tot}}$ represents the share of the income of employed-low-skilled workers in total income

$\tau_3 = \frac{I^U_L}{I_{tot}}$ represents the share of the income of unemployed-low-skilled workers in the total income

$\tau_4 = \frac{I_{HT}}{I_{tot}}$ represents the share of the income of all high-skilled workers in the total income

$\tau_5 = t_D\frac{D_{tot}}{I_{tot}}$ represents the share of revenues from taxes on dirty goods in the total income and

$\tau_6 = \frac{c\,l}{I_{tot}}$ represents the share of the cost of posting vacant jobs in total income.

C_{tot} and D_{tot} denote the total consumption of clean and dirty goods, respectively, whereas $I_{tot} = I_{HT} + I^E_{LT} + I^U_L$ represents the total income of both low and high-skilled workers. Additionally, $I_{HT} = (1-t_H)NHw_H$ represents the income of high-skilled workers, $I^E_{LT} = (1-t_L)lw_L$ represents the income of low-skilled workers when employed while, $I^U_L = (1 - l)\,B$ represents their income when they are unemployed.

Considering change in the consumption of dirty goods as given by equation (28), it becomes evident that achieving the environmental dividend is a complex undertaking. The sign of this variation depends on three effects. A negative effect linked to labor taxes, $-\left(2\,\tau_2\,\tilde{t}_L + 2\,\tau_3\,\frac{q(\theta)}{1-q(\theta)}\right)\tilde{l} - 2\,\tau_4\,\tilde{t}_H\,\tilde{h}$, an ambiguous effect linked to the variation in real wages, $-2\,\tau_2\,\tilde{t}_L\,\tilde{w}_L - 2\,\tau_4\,\tilde{t}_H\,\tilde{w}_H$, and positive effect linked to the increase in purchasing power driven by the impact of subsidies, $(\tau - \tau_1)\,ds + 2\,s\left(\tau_2\,\frac{\tilde{t}_L}{t_L} + \frac{\tau_6}{q(\theta)}\right)\tilde{l} + 2\,s\,\tau_4\,\frac{\tilde{t}_H}{t_H}\,\tilde{h}$. This latter can be broken down into two effects. An effect linked to a greater share of non-polluting goods in the household consumption basket, $(\tau - \tau_1)\,ds$, and an effect linked to the rise in employment, $2\,s\left(\tau_2\,\frac{\tilde{t}_L}{t_L} + \frac{\tau_6}{q(\theta)}\right)\tilde{l} + 2\,s\,\tau_4\,\frac{\tilde{t}_H}{t_H}\,\tilde{h}$. Therefore, although the consumption of polluting goods shows a decline due to labor taxes, it is important to acknowledge that the increase in purchasing power, driven by the impact of subsidies, contributes to sustain it. Consequently, we arrive at the following observation concerning the environmental dividend :

Proposition 2. *By implementing an environmental policy that taxes polluting goods while subsidizing non-polluting ones, consumption of polluting goods tends to decrease. However, an unintended feedback effect emerges due to the increased purchasing power resulting from the positive impact of subsidies on employment and the consumption of non-polluting goods. If the two types of goods are not perfect substitutes, this rise in purchasing power can lead to greater consumption of polluting goods, thereby limiting improvements in environmental quality*

4.3 Distributional consequence

In evaluating environmental policies, another crucial aspect that is often considered is their impact on households' welfare. To assess this effect, we use the concept of marginal excess burden. Following Chiroleu-Assouline and Fodha (2014); Aubert and Chiroleu-Assouline (2019); Zhou et al. (2020), marginal excess burden is defined as the compensatory income variation or an additional income that needs to be provided to the representative household to keep his utility at its initial level after the implementation of the environmental tax reform. It is interpreted as the hidden costs of financing public spending and stands for the excess welfare loss of the consumers over and above the tax revenues collected by the government. Hence, a positive value for the marginal excess burden indicates a decrease in household welfare following the environmental tax reform, while a negative excess burden suggests an improvement in households' welfare after the reform is implemented. We begin our analysis by examining the effects of the policy on high-skilled workers, followed by an assessment of its impact on low-skilled workers. Lastly, we determine whether the policy is progressive or regressive by comparing the excess burden experienced by the two categories of households considered in this study.

Defining d_{R_H} as the compensation income for hig-skilled worker, we show, in appendix H, that this income amounts

$$d\,R_H \;=\; -\;I_H\,\tilde{w}_H \;-\; I_H\left[\frac{1-\sigma}{1-s}-\frac{\sigma}{1+t_D}\right]d\,t_D \\ +\;(1-\sigma)\;\bar{D}\;\left[\frac{1+t_D}{1-s}+1\right]\;d\,t_D-\frac{\partial\,V_H}{\partial\,D_{tot}}\;P_Q\;dD_{tot}. \quad (29)$$

As observed, this compensatory income is broken down into what economists refer to as "use-side" and "source-side" effects, along with the marginal social damage from the consumption of dirty goods. The source-side effect refers to the impact on labor income and is represented by $I_H\;\tilde{w}_H$. Regarding the use-side effect, it corresponds to variations in purchasing power resulting from change in prices of goods consumed (Goulder et al., 2019). This effect is captured by $(C_H-D_H)\,dt_D = I_H\left[\frac{1-\sigma}{1-s}-\frac{\sigma}{1+t_D}\right]dt_D-(1-\sigma)\bar{D}\left[\frac{1+t_D}{1-s}+1\right]dt_D$ in equation (29). Finally, the remaining term, $\frac{\partial\,V_H}{\partial\,D_{tot}}P_Q\;dD_{tot}$, represents the marginal social damage resulting from the consumption of dirty goods. Similarly, compensatory income variations for low-skilled household is given by,

$$d\,R_L = -\;I_L^E\;l\;\tilde{w}_L - P_Q\left[V_L^E - V_L^U\right]\;dl -\;I_L\left[\frac{1\;-\;\sigma}{1\;-\;s}\;-\;\frac{\sigma}{1\;+\;t_D}\right]d\,t_D \\ +\;(1\;-\;\sigma)\;\bar{D}\;\left[\frac{1\;+\;t_D}{1\;-\;s}\;+\;1\right]\;dt_D-\frac{\partial\,V_L}{\partial\,D_{tot}}\;P_Q\;dD_{tot} \quad (30)$$

where the source-side effect is given by $I_L^E\;l\;\tilde{w}_L$; the use-side effect is given by $I_L\left[\frac{1-\sigma}{1-s}\;-\;\frac{\sigma}{1+t_D}\right]dt_D-$

$(1 - \sigma)\, \bar{D}\, \left[\frac{1+t_D}{1-s} + 1\right] dt_D$ and $\frac{\partial\, V_L}{\partial\, D_{tot}}\, P_Q\, dD_{tot}$ is the marginal social damage resulting from the consumption of dirty goods. In addition to these three effects, there is another effect defined as the employment effect represented by $P_Q \left(V_L^E - V_L^U\right) dl$.

Having established the various effects for both low and high-skilled workers, we can now assess the impact of the policy impact on the welfare of each household category. In this evaluation, we adopt a similar assumption as Aubert and Chiroleu-Assouline (2019), by considering that the regressivity of environmental policy only appears through the loss of purchasing power, proportional to the income of the agents. Consequently, we abstract the impact of environmental damage, which is assumed to affect all individuals equally $(\frac{\partial\, V_L}{\partial\, D_{tot}}\, P_Q\, dD_{tot} = \frac{\partial\, V_H}{\partial\, D_{tot}}\, P_Q\, dD_{tot})$, as well as the impact of the minimum requirement of dirty goods, denoted by $(1-\sigma)\bar{D}\left[\frac{1+t_D}{1-s} + 1\right] dt_D$.

Regarding the different impacts, it would be challenging to advocate for an explicit increase or decrease in household welfare. Nevertheless, what can be reasonably asserted is that the policy, via the subsidy, contributes to enhance the purchasing power of households when they prioritize the consumption of clean goods over polluting goods $(1 - \sigma > \sigma)$. The employment effect, is by definition positive $(P_Q \left(V_L^E - V_L^U\right) > 0)$, as a low-skilled worker will not participate in the labor market if the gain from doing so is less than the gain from remaining outside of it. Thus, if the policy succeeds in increasing wages, for low-skilled workers, such that $\tilde{w}_L > 0$, such category of households will experience a welfare enhancing, since the compensatory income,$d\ R_L$, in that case becomes negative. Similarly, if the policy effects on wages is positive for high-skilled workers, such that $\tilde{w}_H > 0$, and the consumption of clean goods of that category of households outweighs their consumption of dirty goods, then the policy leads to an increase in their purchasing power. However, the effect of the policy on wages is ambiguous, since we cannot determine whether the policy contributes to a decrease or increase in wages. The only effect that we can be certain of is a decrease in the reservation wage, w_R, and the consumer price index, P_Q. In conclusion, we say that :

Proposition 3. *Irrespective of their category, households that prioritize clean goods over dirty goods will experience an improvement in welfare if the policy succeeds in raising* *their wage. Nonetheless, if the policy results in a decrease in wages, achieving an overall enhancement in welfare requires two different scenarios*:

1. *For a high-skilled worker, the gain from valuing clean goods more than dirty goods must outweigh the loss incurred from the wage reduction* :
   $-I_H \tilde{w}_H < I_H \left[\frac{1-\sigma}{1-s} - \frac{\sigma}{1+t_D}\right] dt_D$

2. *For a low-skilled worker, both the gain from valuing clean goods more than dirty goods and the gain from entering the labor market must outweigh the loss incurred from the wage reduction* :
   $-I_L^E l \tilde{w}_L < P_Q \left[V_L^E - V_L^U\right] dl + I_L \left[\frac{1-\sigma}{1-s} - \frac{\sigma}{1+t_D}\right] dt_D.$

To further assess the impact of our policy in terms of progressivity or regressivity, we express equation (30) as a function of the bargaining power of low-skilled workers and the elasticity of the matching function with respect to the tightness of the labor market. After abstracting the impact of environmental damage and the impact of the minimum requirement of dirty goods, this equation becomes,

$$d \ R_L = -I_L^E \ l \left(\frac{\beta}{\xi} \frac{p_L}{w_L} \tilde{p}_L + \frac{\xi - \beta}{\xi} \frac{w_R}{w_L} \tilde{w}_R\right) - I_L \left[\frac{1-\sigma}{1-s} - \frac{\sigma}{1+t_D}\right] d \ t_D, \quad (31)$$

where ξ represents the elasticity of matching function with respect to the tightness of labor market, $\theta = \frac{v}{1}$. Both β and ξ are constant and given on the $[0,1]$ interval. Even with equation (31), it is not possible to make definitive statements about the welfare improvement for low-skilled workers, as the impact of the policy on the productivity of low-skilled workers, P_L, is ambiguous. As Aubert and Chiroleu-Assouline (2019), we define the regressivity only in terms of purchasing power. Thus,

Definition 1. *The policy is regressive if and only if the relative loss of purchasing power caused by an increase of the tax rate is lower for high-skilled than for low-skilled workers.*

Following this definition, our policy is regressive if and only if $\frac{d\,R_H}{I_H\, d\,td} < \frac{d\,R_L}{I_L^E\, d\,t_D}$. This implies that,

$$-\frac{\tilde{w}_H}{d\,t_D} < -\frac{I_L^E\, l}{I_L} \left(\frac{\beta}{\xi} \frac{p_L}{w_L} \frac{\tilde{p}_L}{dt_D} + \frac{\xi - \beta}{\xi} \frac{w_R}{w_L} \frac{\tilde{w}_R}{dt_D}\right). \quad (32)$$

Regarding this condition, the problem of regressivity of the policy turns out to its impacts on wages of households and the gain that low-skilled workers obtain in entering in labor market. Although our policy is novel, the conditions for policy neutrality remain unchanged and align with those listed by Aubert and Chiroleu-Assouline (2019). Indeed, our findings indicate that household purchasing power remains unaffected when unemployment levels are efficient ($\beta = \xi$) and the labor market is competitive for both low-skilled and high-skilled workers ($\tilde{w}_H = \tilde{p}_L = 0$). However, due to the constant nature of parameters β and ξ, the efficiency of unemployment is not guaranteed and is satisfied by accident (Heijdra and Ligthart, 2009).

5 Conclusion and Policy Implications

The impact of the existing tax system and the chosen tax rate cuts, which accompany the rise in green taxes, significantly influences the magnitude of the environmental dividend. While the conventional approach to environmental tax reform involves utilizing the revenues from environmental taxes to reduce distortionary labor taxes, we have taken a different approach in this paper. Instead, we propose an environmental tax system coupled with a subsidy to clean goods. We have adopted a general equilibrium framework augmented with search and matching model similar to Aubert and Chiroleu-Assouline (2019). In this model, workers are heterogeneous, labor markets are imperfect, and there is pollution resulting from the consumption dirty goods.

Under the assumption that the preferences of households for clean goods outweigh their preferences for dirty goods, we show that implementing an environmental policy that combines taxes on polluting goods with subsidies for the consumption of clean goods, leads to an increase in employment for both low-skilled and high-skilled workers. This rise in employment stems from the augmented purchasing power due to a greater decline in prices compared to wages that provides households with incentives to work more. Regarding the environmental dividend, our analysis demonstrates that the combination of taxes with subsidies initially leads to a decrease in the consumption of polluting goods. However, an unintended feedback effect arises due to the increased purchasing power resulting from subsidies. If the two kinds of goods are not perfect substitutes, this gain in purchasing power can trigger an increase in the consumption of polluting goods, thereby hindering improvement in the quality of the environment. Concerning welfare effects, we show that, irrespective of their category, households who prioritize clean goods over dirty goods will experience an improvement in welfare if the policy succeeds in raising their wages. Nonetheless, if the policy results in a decrease in wages, achieving an overall enhancement in welfare requires two different scenarios : (i) For a high-skilled worker, the gain from valuing clean goods more than dirty goods must outweigh the loss incurred from the wage reduction; (ii) For a low-skilled worker, both the gain from valuing clean goods more than dirty goods, and the gain from entering the labor market, must outweigh the loss incurred from the wage reduction.

These theoretical results align with existing empirical studies, such as the analysis of the "Bonus/Malus "policy in France introduced in 2008, which showed that although this policy led to a considerable shift towards less polluting cars, its overall environmental impact was negative due to the initial design of fiscal incentives (d'Haultfoeuille et al., 2014). Our study offers a theoretical contribution by explaining the mechanisms behind these observed empirical results, particularly how increased purchasing power can counteract the intended environmental benefits. Additionally, although aligning with the results of the study of Verma and Imelda (2023), our study focuses on a policy that does not operate through quantity restrictions and instead allows households the choice to consume both polluting and non-polluting goods. This enables us to assess the success of environmental policies based on household preferences.

One of the major issues with this policy is that there may be obstacles to its implementation, even if households strongly prefer non-polluting goods. For instance, it has been shown that students, renters, and non-homeowners are largely excluded from the deployment of solar photovoltaic panels due to their housing tenure and ownership status (Sovacool et al., 2022). Therefore, for an environmental policy to be successful, the government should undertake reforms to remove these barriers. The study also assumes that preference parameters remain constant. In the real world, where these parameters might be endogenous, our policy's primary implication is that the government should conduct awareness campaigns to promote the adoption of more environmentally friendly goods and services. Such an approach could lead to improved environmental quality and reduced unemployment. Thus, our policy might be more suitable and effective in countries where people are more aware of environmental issues.

While the policy would reduce pollution, there is concern about a potential erosion of the tax base. However, this concern is somewhat mitigated by the positive impact on employment, which expands the labor tax base. Additionally, increased employment reduces government spending on unemployment benefits, generating additional revenue that can be allocated to other purposes.

In our analysis, we assumed that goods are produced by firms employing either low-skilled or high-skilled labor. However, considering a framework with two production sectors—one producing polluting goods using only low-skilled labor and the other producing clean goods using polluting goods as intermediate inputs and high-skilled labor—could yield different effects on employment. Incorporating such an analytical framework could be a potential subject for future research. Additionally, exploring the impact of heterogeneity and changes in consumer preferences on the outcomes of our study would also be an interesting avenue for further research.

A First-order conditions

From the budget constraint $(1 - s)\, C_i + (1 + t_D)\, D_i = I_i$, we derive D_i as, $D_i = \frac{I_i - (1-s)\, C_i}{1+t_D}$. Substituting D_i in the utility function (1), we obtain,

$$Q_i = C_i^{1-\sigma} \left[\frac{I_i - (1 - s)\, C_i}{1 + t_D} - \bar{D} \right]^{\sigma}. \tag{33}$$

The household chooses the amount of C_i that maximizes Q_i. Therefore, the condition, $\frac{\partial Q_i}{\partial C_i} = 0$, implies that,

$$\begin{aligned}(1 - \sigma)\, C_i^{-\sigma} \left[\frac{I_i - (1-s)\, C_i}{1 + t_D} - \bar{D}\right]^{\sigma} \\ - \sigma\, \frac{1-s}{1+t_D}\, C_i^{1-\sigma} \left[\frac{I_i - (1-s)\, C_i}{1+t_D} - \bar{D}\right]^{\sigma - 1} = 0\end{aligned} \quad (34)$$

Solving equation (34) for C_i yields (3). Substituting (3) in D_i yields (4). Using (3) and (4) together yields the indirect utility (5).

B Derivation of high-skilled worker's labour supply

Given equation (5) and using $\Phi(H) = H^{1+1/\eta_H}/(1 + 1/\eta_H)$, we rewrite equation (8) as,

$$V_H = \underset{H}{max} \left[\frac{(1 - t_H)\, H\, w_H - (1 - t_D)\, \bar{D}}{P_Q} - \frac{H^{1+\frac{1}{\eta_H}}}{1 + \frac{1}{\eta_H}}\right] - \zeta(D_{tot}). \quad (35)$$

Deriving V_H with respect to H and equating the output to zero yields $\frac{(1-t_H)\, W_H}{P_Q} - H^{\frac{1}{\eta_H}} = 0$, from which equation (9) follows.

C Program of maximization

The representative firm program of maximization,

$$\pi(y) = \max_{l,h} \left[y - l\, w_L - w_H\, h - c\, v\right] \quad \text{s.t} \quad (36)$$

$$y = f(l, h) = l^{\alpha}\, h^{1-\alpha} \quad \text{with} \quad 0 < \alpha < 1 \quad \text{and} \quad (37)$$

$$l = \theta\, q(\theta) \quad (38)$$

Since $\theta = \frac{v}{1}$, we derive from (38) that $v = \frac{l}{q(\theta)}$. Substituting y and v by their respective expressions in 36, the program of maximization becomes,

$$\pi(y) = \max_{l,h} \left[l^{\alpha} \, h^{1-\alpha} - l \, w_L - w_H \, h - l \, \frac{c}{q(\theta)} \right]. \tag{39}$$

When deriving with respect to l and using the first-order conditions, we find that, $\alpha \, l^{\alpha-1} \, h^{1-\alpha} - w_L - \frac{c}{q(\theta)} = 0$. Since $\alpha \, l^{\alpha-1} \, h^{1-\alpha} = \frac{\partial f}{\partial l} = p_L$, we obtain, after rearrangement, that $p_L = w_L + \frac{c}{q(\theta)}$. Hence, equation (12). The remainder equation (13) also results from the first-order condition $(1 - \alpha) \, l^{\alpha} \, h^{-\alpha} - w_H = 0$ where $(1 - \alpha) \, l^{\alpha} \, h^{-\alpha} = \frac{\partial f}{\partial h} = p_H$.

D Low-skilled worker wage determination

One may rewrite equation (14) as,

$$\begin{aligned} w_L &= argmax \left\{ \left[Q_L^* \, [(1 - t_L) \, w_L] - [Q_L^*(B) + Z] \right]^{\beta} \left[p_L - w_L \right]^{1-\beta} \right\} \\ &= argmax \left\{ \left[\frac{(1 - t_L) \, w_L - B}{P_Q} - Z \right]^{\beta} [p_L - w_L]^{1-\beta} \right\} \end{aligned}$$

$$\begin{aligned} \Rightarrow \quad & \beta \frac{1 - t_L}{P_Q} \left[\frac{(1 - t_L) \, w_L - B}{P_Q} - Z \right]^{\beta - 1} \left[p_L - w_L \right]^{1-\beta} - \\ & (1 - \beta) \left[\frac{(1 - t_L) \, w_L - B}{P_Q} - Z \right]^{\beta} \left[p_L - w_L \right]^{-\beta} = 0 \end{aligned}$$

$$\begin{aligned} \Rightarrow \quad & \frac{\beta \frac{1 - t_L}{P_Q}}{\left[\frac{(1 - t_L) \, w_L - B}{P_Q} - Z \right]} - \frac{1 - \beta}{p_L - w_L} = 0 \\ \Rightarrow \quad & \beta \, \frac{\frac{1 - t_L}{P_Q}}{V_L^E - V_L^U} - \frac{1 - \beta}{p_L - w_L} = 0 \end{aligned}$$

Since $p_L = w_L + \frac{c}{q(\theta)}$, we have $\frac{P_Q\left(V_L^E - V_L^U\right)}{1 - t_L} = \frac{c}{q(\theta)} \frac{\beta}{1-\beta}$. This implies that $\frac{\left[(1 - t_L)\, w_L - B - P_Q\, Z\right]}{1 - t_L} = \frac{c}{q(\theta)} \frac{\beta}{1-\beta}$. The reservation wage, w_R, being a wage rate, w_L, such that $V_L^E = V_L^U$, we find that $w_R = \frac{B + P_Q\, Z}{1 - t_L}$. Then we have $w_L - w_R = \frac{c}{q(\theta)} \frac{\beta}{1-\beta} = \frac{\beta}{1-\beta} (p_L - w_L)$. Hence, equation (15).

E Low-skilled labor market

Log-linearized forms of equations (11), (12), and (16) follow:

$$\tilde{l} = (1 - \xi)\, \tilde{\theta} \tag{40}$$

$$\tilde{p}_L = \frac{w_L}{p_L}\, \tilde{w}_L + \frac{c}{q(\theta)} \frac{\xi}{p_L}\, \tilde{\theta} \tag{41}$$

$$\tilde{w}_L = \beta \frac{p_L}{w_L}\, \tilde{p}_L + (1 - \beta)\, \frac{w_R}{w_L}\, \tilde{w}_R \tag{42}$$

where $\xi = -\frac{\partial\, q(\theta)}{q(\theta)} \frac{\theta}{\partial\, \theta}$. From equation (16), we know that $\beta = \frac{w_L - w_R}{p_L - w_R}$. Based on this latter, it follows from equation (42) that:

$$\tilde{w}_L = \frac{w_L - w_R}{p_L - w_R} \frac{p_L}{w_L}\, \tilde{p}_L + \frac{p_L - w_L}{p_L - w_R} \frac{w_R}{w_L}\, \tilde{w}_R. \tag{43}$$

Substituting (43) in (41), we find that

$$\tilde{p}_L = \frac{w_L}{p_L} \left[\frac{w_L - w_R}{p_L - w_R} \frac{p_L}{w_L}\, \tilde{p}_L + \frac{p_L - w_L}{p_L - w_R} \frac{w_R}{w_L}\, \tilde{w}_R\right] + \frac{c}{q(\theta)} \frac{\xi}{p_L}\, \tilde{\theta}. \tag{44}$$

Making use of $p_L = w_L + \frac{c}{q(\theta)}$, we show that

$$\tilde{p}_L = \frac{w_L}{p_L} \left[\frac{w_L - w_R}{p_L - w_R} \frac{p_L}{w_L}\, \tilde{p}_L + \frac{p_L - w_L}{p_L - w_R} \frac{w_R}{w_L}\, \tilde{w}_R\right] + [p_L - w_L]\, \frac{\xi}{p_L}\, \tilde{\theta}. \tag{45}$$

When solving for $\tilde{\theta}$, we find

$$\tilde{\theta} = \frac{\tilde{p}_L \frac{p_L}{p_L - w_R} - \frac{w_R}{p_L - w_R}\, \tilde{w}_R}{\xi}. \tag{46}$$

Substituting (46) in (40) we obtain,

$$\tilde{l} = \frac{1 - \xi}{\xi} \frac{p_L}{p_L - w_R} \tilde{p}_L - \frac{1 - \xi}{\xi} \frac{p_L}{p_L - w_R} \frac{w_R}{p_L} \tilde{w}_R. \tag{47}$$

Change in reservation wage w_R is expressed as,

$$\tilde{w}_R = \frac{P_Q\, Z}{B + P_Q\, Z} \left[\frac{\sigma}{1 + t_D} - \frac{1 - \sigma}{1 - s}\right] dt_D. \tag{48}$$

After taking account this latter equation, we find from equation (47), equation (24).

F Proof of proposition 1

The policy has a positive impact on employment if both $\tilde{h}^* > 0$ and $\tilde{l}^* > 0$. Since, $(1 + \alpha\, \eta_H)\eta_R > 0$, $(1 - \alpha)\eta_L \eta_H > 0$, $\alpha \eta_H \eta_R > 0$, $(1 + (1 + \alpha)\eta_L)\, \eta_H > 0$ and $1 + (1 - \alpha)\eta_L + \alpha \eta_H > 0$; and changes in the reservation wage, $\tilde{w}_R$, and consumer price index, $\tilde{P}_Q$, are negatively correlated with changes in employment, the scenarios which are favorable for employment are when $\tilde{P}_Q < 0$ and $\tilde{w}_R < 0$. Since $1 + t_D > 1 - s$, both $\tilde{P}_Q$ and $\tilde{w}_R$ are negative if, $\sigma < (1 - \sigma)$ as implied by assumption 2.

G Environmental dividend

The log-linearization of the budget constraint yields

$$dG = G_s\, ds + G_{t_D}\, dt_D$$

where,

$$G_{t_D} = \frac{\left[\begin{array}{l} D_{tot} + l\, w_L\, t_L \left(\frac{\partial\, w_L}{w_L\, \partial\, t_D} + \frac{\partial\, l}{l\, \partial\, t_D}\right) + N\, H\, w_H\, t_H \left(\frac{\partial\, w_H}{w_H\, \partial\, t_D} + \frac{\partial\, H}{H\, \partial\, t_D}\right) \\ \quad + B\, l\, \frac{\partial\, l}{l\, \partial\, t_D} + t_D\, D_{tot}\, \frac{\partial\, D_{tot}}{D_{tot}\, \partial\, t_D} - s \left(p_L\, l\, \frac{\partial\, l}{l\, \partial\, t_D} + N\, H\, p_H\, \frac{\partial\, H}{H\, \partial\, t_D}\right) \end{array}\right]}{1 - s} \tag{49}$$

and

$$G_s = \frac{\left[\begin{array}{r} G + D_{tot} - y + l\, w_L\, t_L \left(\frac{\partial\, w_L}{w_L\, \partial\, s} + \frac{\partial\, l}{l\, \partial\, s}\right) + N\ H\ w_H\, t_H \left(\frac{\partial\, w_H}{w_H\, \partial\, s} + \frac{\partial\, H}{H\, \partial\, s}\right) \\ + B\, l\, \frac{\partial\, l}{l\, \partial\, s} \ + \ s\ D_{tot}\, \frac{\partial\, D_{tot}}{D_{tot}\, \partial\, s} - s\left(p_L\ l\, \frac{\partial\, l}{l\, \partial\, s} + N\ H\ p_H\, \frac{\partial\, H}{H\, \partial\, s}\right) \end{array}\right]}{1\ -\ s} \tag{50}$$

When multiplying both sides of the equation (49) by dt_D, we find that

$$G_{t_D}\ dt_D = \frac{\left[\begin{array}{r} D_{tot}\ dt_D + \ l\ w_L\ t_L\ \left(\tilde{w}_L + \tilde{l}\right) + N\ H\ w_H\ t_H\ \left(\tilde{w}_H + \tilde{h}\right) \\ + B\ l\ \ \tilde{l}\ + \ t_D\ \tilde{D}_{tot} - s\ \left(p_L\ l\ \tilde{l} + N\ H\ p_H\ \tilde{h}\right) \end{array}\right]}{1\ -\ s}$$

We define $I^E_{LT} = (1-t_L)lw_L$, $I_{HT} = (1-t_H)NHw_H$, $I^U_L = (1-l)B$. With $p_L = w_L + \frac{c}{q(\theta)}$ and $p_H = w_H$, we can express $G_{t_D}\ dt_D$ as,

$$G_{t_D}\ dt_D = \frac{\left[\begin{array}{r} D_{tot}\ dt_D + I^E_{LT}\ \frac{t_L}{1-t_l}\ \left(\tilde{w}_L + \tilde{l}\right) + I_{HT}\ \frac{t_H}{1-t_H}\ \left(\tilde{w}_H + \tilde{h}\right) \\ + \ I^U_L\, \frac{l}{1-l}\ \tilde{l}\ + \ t_D\ D_{tot}\ \tilde{D}_{tot} - s\ \left(\frac{I^E_L}{1-t_L}\ \tilde{l} + \frac{c\, l}{q(\theta)}\ \tilde{l} + \frac{I_H}{1-t_H}\ \tilde{h}\right) \end{array}\right]}{1\ -\ s}$$

Let $\tilde{t}_L = \frac{t_L}{1-t_L}$, $\tilde{t}_H = \frac{t_H}{1-t_H}$, this implies that $\frac{1}{1-t_H} = \frac{\tilde{t}_H}{t_H}$ and $\frac{1}{1-t_L} = \frac{\tilde{t}_L}{t_L}$. Defining $I_{tot} = (1-t_L)lw_L + (1-l)B + (1-t_H)NHw_H$, it follows that,

$$\frac{G_{t_D}\ dt_D}{I_{tot}} = \frac{\left[\begin{array}{r} \frac{D_{tot}}{I_{tot}}\ dt_D + \frac{I^E_{LT}}{I_{tot}}\ \tilde{t}_L\ (\tilde{w}_L + \tilde{l}) + \frac{I_{HT}}{I_{tot}}\ \tilde{t}_H\ (\tilde{w}_H + \tilde{h}) + \ \frac{I^U_L}{I_{tot}}\frac{l}{1-l}\ \tilde{l} \\ + \ \frac{t_D\ D_{tot}}{I_{tot}}\ \tilde{D}_{tot} - s\ \left(\frac{I^E_L}{I_{tot}}\ \frac{\tilde{t}_L}{t_L}\ \tilde{l} + \frac{c\, l}{q(\theta)\ I_{tot}}\ \tilde{l} + \frac{I_H}{I_{tot}}\ \frac{\tilde{t}_H}{t_H}\ \tilde{h}\right) \end{array}\right]}{1\ -\ s}$$

Defining $\tau_1 = \frac{D_{tot}}{I_{tot}}$, $\tau_2 = \frac{I^E_{LT}}{I_{tot}}$, $\tau_3 = \frac{I^U_L}{I_{tot}}$, $\tau_4 = \frac{I_{HT}}{I_{tot}}$, $\tau_5 = t_D\frac{D_{tot}}{I_{tot}}$ and $\tau_6 = \frac{c\, l}{I_{tot}}$, we finally find that,

$$\frac{G_{t_D}\ dt_D}{I_{tot}} = \frac{\left[\begin{array}{r} \tau_1\ dt_D + \tau_2\ \tilde{t}_L\ (\tilde{w}_L + \tilde{l}) + \tau_4\ \tilde{t}_H\ (\tilde{w}_H + \tilde{h}) + \ \tau_3\frac{l}{1-l}\ \tilde{l} \\ + \ \tau_5\ \tilde{D}_{tot} - s\ \left(\tau_2\frac{\tilde{t}_L}{t_L}\ \tilde{l} + \frac{\tau_6}{q(\theta)}\ \tilde{l} + \tau_4\frac{\tilde{t}_H}{t_H}\ \tilde{h}\right) \end{array}\right]}{1\ -\ s}$$

After some rearrangement, we obtain that,

$$\frac{G_{t_D}\ dt_D}{I_{tot}} = \frac{\begin{bmatrix} \tau_2\ \tilde{t}_L\ \tilde{w}_L + \tau_4\ \tilde{t}_H\ \tilde{w}_H + \tau_1\ dt_D +\ \tau_5\ \tilde{D}_{tot} \\ +\left(\tau_2\ \tilde{t}_L + \tau_3 \frac{l}{1-l} - s\ \tau_2\ \frac{\tilde{t}_L}{t_L} - s\ \frac{\tau_6}{q(\theta)}\right)\ \tilde{l} + \left(\tau_4\ \tilde{t}_H - s\ \tau_4\ \frac{\tilde{t}_H}{t_H}\right)\tilde{h} \end{bmatrix}}{1\ -\ s}$$

Following the same steps for G_s, we arrive at

$$\frac{G_s\ ds}{I_{tot}} = \frac{\begin{bmatrix} \tau_2\ \tilde{t}_L\ \tilde{w}_L + \tau_4\ \tilde{t}_H\ \tilde{w}_H + s\ \tau_1\ \tilde{D}_{tot} - \tau\ ds \\ +\left(\tau_2\ \tilde{t}_L + \tau_3 \frac{l}{1-l} - s\ \tau_2\ \frac{\tilde{t}_L}{t_L} - s\ \frac{\tau_6}{q(\theta)}\right)\ \tilde{l} + \left(\tau_4\ \tilde{t}_H - s\ \tau_4\ \frac{\tilde{t}_H}{t_H}\right)\tilde{h} \end{bmatrix}}{1\ -\ s}$$

Then, considering that $\frac{dG}{I_{tot}} = \frac{G_s\ ds}{I_{tot}} + \frac{G_{t_D}\ dt_D}{I_{tot}}$, we obtain that,

$$\frac{dG}{I_{tot}} = \frac{\begin{bmatrix} 2\ \tau_2\ \tilde{t}_L\ \tilde{w}_L + 2\ \tau_4\ \tilde{t}_H\ \tilde{w}_H + \tau_1\ dt_D - \tau\ ds + (\tau_5 +\ s\ \tau_1)\ \tilde{D}_{tot} \\ +2\left(\tau_2\ \tilde{t}_L + \tau_3 \frac{l}{1-l} - s\ \tau_2\ \frac{\tilde{t}_L}{t_L} - s\ \frac{\tau_6}{q(\theta)}\right)\ \tilde{l} + 2\left(\tau_4\ \tilde{t}_H - s\ \tau_4\ \frac{\tilde{t}_H}{t_H}\right)\tilde{h} \end{bmatrix}}{1\ -\ s}$$

Solving $\frac{dG}{I_{tot}} = 0$ for $\tilde{D}_{tot}$ and making use of assumption 1 ($dt_D = ds$), we find that,

$$\tilde{D}_{tot} = \frac{\begin{bmatrix} -\left(2\ \tau_2\ \tilde{t}_L + 2\ \tau_3\ \frac{q(\theta)}{1-q(\theta)}\right)\tilde{l} - 2\ \tau_4\ \tilde{t}_H\ \tilde{h} - 2\ \tau_2\ \tilde{t}_L\tilde{w}_L - 2\ \tau_4\ \tilde{t}_H\tilde{w}_H \\ +(\tau - \tau_1)\,ds\ +\ 2\ s\left(\tau_2\frac{\tilde{t}_L}{t_L}\ +\ \frac{\tau_6}{q(\theta)}\right)\tilde{l}\ +\ 2\ s\ \tau_4\ \frac{\tilde{t}_H}{t_H}\ \tilde{h} \end{bmatrix}}{\tau_5\ +\ s\ \tau_1}$$

H Derivation of marginal excess burden for low-skilled and high-skilled workers

The marginal excess burden which represents the compensatory income variation or an additional income that needs to be provided to the representative household to keep his utility at its initial level. So, $d\ V_H = d\ V_L = 0$.

H.1 High-skilled worker

$$V_H = Max\left[\frac{(1-s)\,C_H + (1+t_D)\,D_H - (1+t_D)\,\bar{D}}{P_Q} - \frac{H^{1+\frac{1}{\eta_H}}}{1+\frac{1}{\eta_H}}\right] - \zeta(D_{tot}) \quad (51)$$

$$dV_H = \frac{\partial\, V_H}{\partial\, C_H}\,dC_H + \frac{\partial\, V_H}{\partial D_H}\,dD_H + \frac{\partial\, V_H}{\partial\, H}\,dH + \frac{\partial\, V_H}{\partial\, D_{tot}}\,dD_{tot} \quad (52)$$

$$d\,V_H = \frac{1-s}{P_Q}\,d\,C_H + \frac{1+t_D}{P_Q}\,d\,D_H - \frac{(1-t_H)\,w_H}{P_Q}\,d\,H + \frac{\partial\, V_H}{\partial\, D_{tot}}\,d\,D_{tot} \quad (53)$$

When solving $d\,V_H = 0$ for $d\,C_H$, we obtain,

$$d\,C_H = \frac{(1-t_H)\,w_H}{1-s}\,d\,H - \frac{1+t_D}{1-s}\,d\,D_H - \frac{\partial\, V_H}{\partial\, D_{tot}}\,d\,D_{tot} \quad (54)$$

High-skilled worker's budget constraint with the compensatory income is:

$$(1-s)\,C_H + (1+t_D)\,D_H = w_H\,(1-t_H)\,H + R_H \quad (55)$$

where R_H is the compensatory income. Differentiation of the budget constraint yields:

$$d\,R_H = (1-s)\,d\,C_H + (1+t_D)\,d\,D_H + (D_H - C_H)\,d\,t_D - w_H\,(1-t_H)\,d\,H + H\,w_H\,d\,t_H - (1-t_H)\,H\,d\,w_H \quad (56)$$

Making use of 54, equation 56 becomes:

$$d\,R_H = -\left[I_H\,\tilde{w}_H + (C_H - D_H)\,d\,t_D\right]. \quad (57)$$

Given that $C_i = \frac{1-\sigma}{1-s} \left[I_i - (1 + t_D) \bar{D} \right]$ and $D_i = \frac{\sigma}{1+t_D} \left[I_i - (1 + t_D) \bar{D} \right] + \bar{D}$, it follows that

$$C_H - D_H = \left[\frac{1 - \sigma}{1 - s} - \frac{\sigma}{1 + t_D} \right] I_H - (1 - \sigma) \bar{D} \left[\frac{1 + t_D}{1 - s} + 1 \right]. \tag{58}$$

Then, combining equations 57 and 58, we obtain that

$$\begin{aligned} d R_H = & - I_H \tilde{w}_H - I_H \left[\frac{1-\sigma}{1-s} - \frac{\sigma}{1+t_D} \right] d t_D \\ & + (1-\sigma) \bar{D} \left[\frac{1+t_D}{1-s} + 1 \right] d t_D - \frac{\partial V_H}{\partial D_{tot}} \frac{P_Q}{1-s} D_{tot} \tilde{D}_{tot} \end{aligned} \tag{59}$$

which is the same with equation 29.

H.2 Low-skilled workers

$$V_L = (1-l) \left[\frac{(1-s) C_L^U + (1+t_D) D_L^U - (1+t_D) \bar{D}}{P_Q} + Z \right]$$

$$+ l \left[\frac{(1-s) C_L^E + (1+t_D) D_L^E - (1+t_D) \bar{D}}{P_Q} \right] - \zeta(D_{tot})$$

$$d V_L = \frac{\partial V_L}{\partial C_L^U} d C_L^U + \frac{\partial V_L}{\partial C_L^E} d C_L^E + \frac{\partial V_L}{\partial l} d l$$

$$+ \frac{\partial V_L}{\partial D_L^E} d D_L^E + \frac{\partial V_L}{\partial D_L^U} d D_L^U + \frac{\partial V_L}{\partial D_{tot}} d D_{tot}$$

$$= \left[\begin{aligned} (1-l) \tfrac{1-s}{P_Q} d C_L^U + l \tfrac{1-s}{P_Q} d C_L^E + \tfrac{\partial V_L}{\partial D_{tot}} d D_{tot} \\ + (1-l) \tfrac{1+t_D}{P_Q} d D_L^U + l \tfrac{1+t_D}{P_Q} d D_L^E \end{aligned} \right]$$

$$+ \left[\begin{aligned} \left[\tfrac{(1-s) C_L^E + (1+t_D) D_L^E - (1+t_D) \bar{D}}{P_Q} \right] \\ - \left[\tfrac{(1-s) C_L^U + (1+t_D) D_L^U - (1+t_D) \bar{D}}{P_Q} + Z \right] \end{aligned} \right] dl$$

This implies that,

$$d\,V_L = \frac{1\,-\,s}{P_Q}\;\left[l\,d\,C_L^E\,+\,(1\,-\,l)\,d\,C_L^U\right]\,+\,\frac{1\,+\,t_D}{P_Q}\left[l\,d\,D_L^E\,+\,(1\,-\,l)\,d\,D_L^U\right]$$
$$+\left[V_L^E\,-\,V_L^U\right]\,dl\,+\,\frac{\partial V_L}{\partial\,D_{tot}}\,dD_{tot},$$

where,

$V_L^E \equiv \frac{(1-s)\,C_L^E+(1+t_D)\,D_L^E-(1+t_D)\,\bar{D}}{P_Q}, \quad V_L^U \equiv \frac{(1-s)\,C_L^U+(1+t_D)\,D_L^U-(1+t_D)\,\bar{D}+P_Q\,Z}{P_Q}.$

When solving $d\,V_L = 0$ for $l\,d\,C_L^E\,+\,(1\,-\,l)\,d\,C_L^U$, we obtain that,

$$l\,d\,C_L^E\,+\,(1\,-\,l)\,d\,C_L^U = -\,\frac{1\,+\,t_D}{1\,-\,s}\;\left[l\,d\,D_L^E\,+\,(1\,-\,l)\,d\,D_L^U\right] \tag{60}$$
$$-\,\frac{P_Q}{1\,-\,s}\;\left[V_L^E\,-\,V_L^U\right]\,dl\,-\,\frac{P_Q}{1\,-\,s}\,\frac{\partial\,V_L}{\partial\,D_{tot}}\,dD_{tot}. \tag{61}$$

The budget constraint of a low-skilled worker is:

$$(1\,-\,l)\;\left[(1\,-\,s)\,C_L^U\,+\,(1\,+\,t_D)\,D_L^U\right]\,+\,l\;\left[(1\,-\,s)\,C_L^E\,+\,(1\,+\,t_D)\,D_L^E\right]$$
$$=\,(1\,-\,l)\,B\,+\,l\,w_L(1\,-\,t_L)\,+\,R_L \tag{62}$$

where R_L is the compensatory income. Differentiation of the budget constraint yields:

$$[I_L^E - B]dl + [D_L - C_L]dt_D + (1-s)\left[(1-l)dC_L^U + ldC_l^E\right] + (1+t_D)\left[(1-l)dD_L^U + ldD_L^E\right]$$
$$= [(1-t_L)\,w_L - B]\;dl\,+\,I_L^E\,l\,\left[\tilde{w}_L - \frac{d\,t_L}{1-t_L}\right] + d\,R_L.$$

When solving for dR_L and considering that $d\;t_L\,=\,0$, we obtain, after using equation (61), that

$$d\,R_L = -\,I_L^E\,l\,\tilde{w}_L - P_Q\;\left[V_L^E - V_L^U\right]\;dl - [C_L - D_L]\;d\,t_D - \frac{\partial\,V_L}{\partial\,D_{tot}}\,P_Q\,dD_{tot} \tag{63}$$

Since $C_L - D_L = \left[\frac{1-\sigma}{1-s} - \frac{\sigma}{1+t_D}\right] I_L - (1-\sigma)\,\bar{D}\left[\frac{1+t_D}{1-s} + 1\right]$, equation (63) becomes,

$$d\,R_L = -\,I_L^E\,l\,\tilde{w}_L - P_Q\left[V_L^E - V_L^U\right]\,dl - I_L\left[\frac{1-\sigma}{1-s} - \frac{\sigma}{1+t_D}\right]d\,t_D$$
$$+\,(1-\sigma)\,\bar{D}\left[\frac{1+t_D}{1-s} + 1\right]dt_D - \frac{\partial\,V_L}{\partial\,D_{tot}}\,P_Q\,dD_{tot} \quad (64)$$

When making abstraction of $(1-\sigma)\,\bar{D}\left[\frac{1+t_D}{1-s} + 1\right]dt_D - \frac{\partial\,V_L}{\partial\,D_{tot}}\,P_Q\,dD_{tot}$ in (64), we obtain that,

$$dR_L = -I_L^E\,l\,\tilde{w}_L - P_Q\left[V_L^E - V_L^U\right]\,dl - I_L\left[\frac{1-\sigma}{1-s} - \frac{\sigma}{1+t_D}\right]dt_D.$$

Dividing this latter result by $I_L dt_D$ with $I_L = (1-t_L)\,l\,w_L + (1-l)\,B$, we obtain that,

$$\frac{d\,R_L}{I_L\,d\,t_D} = -\frac{I_L^E\,l}{I_L}\,\frac{\tilde{w}_L}{d\,td} - \frac{P_Q\,(V_L^E - V_L^U)\,dl}{I_L\,d\,t_D} - \left[\frac{1-\sigma}{1-s} - \frac{\sigma}{1+t_D}\right]. \quad (65)$$

From the wage mark-up (16), we have:

$$P_Q\left[V_L^E - V_L^U\right]dl = \frac{w_L - w_R}{w_L}\,I_L^E l\tilde{l} \quad (66)$$

Making use of $\tilde{w}_L = \beta\,\frac{p_L}{w_L}\,\tilde{p}_L + (1-\beta)\,\frac{w_R}{w_L}\,\tilde{w}_R$ and $\tilde{l} = \frac{1-\xi}{\xi}\,\frac{\beta}{1-\beta}\,\frac{p_L\,\tilde{p}_L - w_L\,\tilde{w}_L}{w_L - w_R}$, we obtain:

$$\frac{dR_L}{I_L\,dt_D} = -\frac{I_L^E l}{I_L}\left(\frac{\beta}{\xi}\frac{p_L}{w_L}\frac{\tilde{p}_L}{dt_D} + \frac{\xi-\beta}{\xi}\frac{w_R}{w_L}\frac{\tilde{w}_R}{dt_D}\right) - \left[\frac{1-\sigma}{1-s} - \frac{\sigma}{1+t_D}\right]. \quad (67)$$

Data Availability Statement

Data not available / No data was used for the research described in the article

Declarations

Confict of interest The authors declare that they have no confict of interest

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