Environmental Taxation, Frictional Unemployment and Migration in a Two-Region Model

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Abstract

This paper investigates how a rise in the pollution tax rate may affect unemployment, migration and welfare in a Harris–Todaro (HT) model. We build a two-regional model with imperfect labor markets, pollution externalities and non-homothetic preferences (Stone-Geary utility) on polluting consumption. This analysis shows that frictional unemployment and non-homothetic preferences bring about inter-region wage differential. Thus, an economy almost always exhibits distortions in the absence of government intervention. Green tax may exacerbate these distorsions by generating spillovers, if the labor market is initially more frictional in the region where the subsistence level of the polluting good is higher. Inter-region transfers that remove distortions, are explored as the solution.

JEL classification: - H23 - J64 - Q52 - Q56 - R13.

Keywords: Environmental tax - Non-Homothetic Preferences - Migration - Unemployment - Welfare analysis

1 Introduction

The political success featured by the agreement met at the COP 21 in Paris, stands as a major turning point in the international cooperation for the preservation of the global environment. But if countries recognize the need to reduce the emissions of greenhouse gases (GHG) in order to limit the ongoing climate change, the way of doing it is still lively discussed. Among the different policy instruments to achieve environmental quality objectives, economists traditionally promote the efficiency of the market-based instruments such as green taxes or cap-and trade. Yet, the introduction of such a carbon price gives rise to many debates and criticisms. Recently, even among economists community, a debate emerged about a global carbon price. Some argue that this would be a perfect tool to promote universal participation and that it would avoide "free-rider" behavior. Many opponents answer that the tax burden of such a price is likely to differ between countries or even areas, underlining the local component of the regressivity of green taxes.

Indeed, countries such as China, India, Mexico, and Chile, have attempted to reduce domestic poverty through industrialization inducing urban-rural migration but also environmental degradation. It is thus of fundamental and practical importance to understand whether poverty reduction through industrialization is consistent with environmental preservation in a emerging economy. On an other side, inside developed countries, opponents to a carbon tax underline its regressivity, as the energy part in the total expenditure of the poor households is larger compared to the one of rich households (Metcalf [1999]). In addition, poorer people seem to have less substitution possibilities between clean and dirty goods, because they live far from city centers and thus do not have access to public transportation or city gaz for instance. Because of this differences in "access cost", the project of a global carbon tax is often considered unfair.

To offset this potential bias, economists suggest to implement transfers between areas, based on income and localization criteria. In fact, the success of the COP 21 would not have been feasible without transfers agreements amoung contries. If a carbon tax reform is to be done, the way the tax proceeds are redistributed is of foremost importance for equity reasons. However, this solution requires information on the local distributive pattern of green taxes.

How does heterogeneity of access to clean goods matter for the equity and the efficiency of the environmental green tax reform? What can be the best option for recycling the revenue from green taxes? Can Migration between urban and areas represent a solution of adaptation? This paper aims at providing a way tlo answer these questions.

Several empirical papers already adressed this issue, underlining the local dimension in the regressivity of green taxes. Sterner [2012] shows that the elasticity of substitution between clean and dirty good seems higher in a rural area compared to urban area in a developed country. More recently, Carraro and Zatti [2014], using a micro-simulation model, show that geographic and social-economic features of households greatly influence redistributive patterns of duties on fuel sources and vehicle taxes. Rural households and large families tend to be affected more within each income quintile. Moreover, richer households are normally those capable of shifting towards more fuel-efficient vehicles. Ciaschini [2012], William [2014], and Hassett [2007] confirm these results by using CGE model.

Yet, to the best of our knowledge, the distribution of green taxes burden has not been extensively analyzed from the perspective of regional inequalities in a theoretical framework. Some environmental economics theoretical works investigate the difficulties of setting an optimal green tax in an economic federation with different regions. These papers refer to fiscal externalities of local governments who compete for workers or capital and generate spillovers (Oates [2002]). This was also studied between national and local governments when the latter transfers its tax burden on the former (Aronsson & al [2004], Williams [2011]). But this emerging literature dealing with environmental federalism does not focus on the disparities in wealth and access to clean good.

On these lines, papers dealing with environmental externality in the context of Harris-Todaro models may represent a contribution.
Harris and Todaro [1970] and related studies have provided a series of models that constitute the received theory of rural-urban migration. Workers are assumed to compare expected incomes in cities with agricultural wages and to migrate if the former exceeds the latter. Migration is the equilibrating force which equates the two. An equilibrium is attained when they are equalized and there is no migration. Although there is an abundant literature about Harris-Todao model, few consider the environmental problem faced by the developing countries. Wang [1990], building on this standard model, demonstrates that a raise in a green tax, increases the agricultural wage and lowers urban unemployment by producing backward migration to the agricultural sector. Recently Daitoh [2003], in a model in which urban manufacturing production exhibits a negative extenality on consumers' utility function, derives the sufficient condition for a rise in the pollution tax rate on urban manufacturing to improve national income.

We intend to complement this short stream of literature to get a larger picture of the regional distributive and efficiency consequences of a environmental tax reform.
To do so, we introduce differences in access to clean goods between regions in the analysis of

an environmental tax reform. Possibility of transfers among different regions are introduced to enhance social welfare regarding the efficiency loss induced by migration's spillovers .

We mainly focus on the paper of Daitoh [2003], to which we add three detrimental assumptions. First, pollution is due to the use of a polluting input in both production processes, that can be also consummed by household. Second, households have a subsistence level of polluting goods that we allow to differ among regions (Jacobs and van der Ploeg [2010]). Third, there is frictional unemployment in both sectors.

In fact, our paper incorporates some features borrowed from papers that merge search generated unemployment literature (introduced by Pissarides [1998]) within a rural-urban migration framework (see for example Sato [2004], Kuralbayeva [2013], Satchi and Temple [2009]). In contrast to the previous studies in the Harris-Todaro framework, they show that frictional urban unemployment causes an inter-sector wage disparity and because of the frictional externalities, the allocation of agents between regions is almost always sub-optimal.

One of our key contributions is to combine frictional unemployment with non-homothetic preferences for the polluting good in an Harris-Todaro economic. We show that a difference in subsistence level of the polluting good among regions may exacerbate the sector-wage disparities due to frictions and this generates spillovers. Moreover, these specifications allow us to work in an ideal framework in order to study the trade-off between efficiency (employment), inter-regional equity (due to perfect mobility) and environmental welfare of an environnmental tax reform. Our paper joints then the migration development literature with the traditional Double Dividend literature (see Bovenberg and de Mooij [1994], Goulder [1995], Bovenberg and Van der Ploeg [1998]).

In a general equilibrium framework, we build a two-sector model, whithin labor is assumed perfectly mobile (Harris-Todaro [1970]) and there is a pollution externality. As in Bovenberg and De Mooij [1994], pollution is due to two different sources: the use, in both of the production processes, of a polluting input; and the consumption of polluting commodities by household. We represent this pollution commodity as necessity (Stone-Geary preferences) and we allow its subsistence level to differ between regions. Both sectors present structural unemployment caused by hiring costs, and we use a static search and matching model to formulate frictions on labor markets with individual worker-firm bargaining. The model is fully solved analytically as we have specified, in the simplest way, preferences and technologies. The main results are the following: frictional unemployment and non-homothetic preferences bring about an inter-region wage differential. Thus, an economy almost always exhibits distortions in the absence of government intervention. A green tax may exacerbate these distotsions by generating spillovers, if the labor market is initially more frictional in the region where the subsistence level of the polluting good is higher. Inter-region transfers that remove distortions, are explored

The remainder of the paper is set out as follows. In the next section we present the basic features of our model. Section 3 solves the general equilibrium, and analyzes the effect of an increase in a green tax on wage disparities, unemployment and migration. In section 4, we examine the effect of green taxation on national income and study the impact of interregional transfers on it. Section 5 concludes.

2 The Model

The model assumes a closed economy made up of two regions, that can be also seen as urban and rural areas (indexed by $i = 1, 2$, in the following). Each of them is specialized in the production of one good , denoted X_i for the region i that are assumed to be imperfect substitutes[1]We treat the good X_2 as a numeraire and let p_1 denote the relative price of the good X_1.

There is a continum of workers of exogenous size $\bar{L}$ in this country. L_1 workers are living in the region 1 and involved in the production of the sector X_1, whereas:

$$L_2 = \bar{L} - L_1 \tag{1}$$

reside in the region 2 and work in the corresponding sector X_2. We assume structural unemployment in both areas caused by hiring costs, and we use a search and matching model to formulate frictions on labor markets with individual worker-firm bargaining. In order to make the analysis as simple as possible, we adopt a static framework[2] We refer to l_i to specify employed workers in the sector X_i. Besides labor considered as perfectly mobile between sector, a second input (E_i) enters the production process of X_i. This input causes environmental damage when used in production. Accordingly, it is called the 'polluting' input (Daitoh [2004]) . Households setting in region i also consumme "C_i^E " as commodities that harms as well the environment. We assume, for simplicity, that the market for E does not exist and that

[1]Throughout the paper, we will refer to the large jurisdiction as a nation and the smaller jurisdictions as regions. But this is just convenient terminology: the model is general, and could just as easily represent areas like urban/rural areas, or city. Yet it can be inconvenient for nations inside a Federal System as European Union.: we don't assume different searching cost for migrants in our model.

[2]As Diamond [1982] showed, we can describe the essence of job search and recruiting externalities using a static model. For examples of static search and matching models, see Sato [2004], Keuschnigg and Ribi [2008].

supra-national government imposes a specific tax t_E on the use of E by firms and consumers (Copeland and Taylor [2004], Rapanos [2007], Daitoh & al [2011]). It uses these tax revenues to provide lump-sum transfers T to each household.

2.1 Households behavior

We use a simple static search and matching framework of labor market to model unemployment among workers. There are heterogeneities (or mismatches) in the labor market that make it costly for a worker or a firm to find a partner with whom they can produce sufficiently high returns (Pissarides [1998]). Labor market heterogeneities are summarized in the matching function that gives the rate at which good matches are formed in the labor market. Given a mass L_i of workers searching a job in the area i, and the number of vacant jobs v_i in this area, in its simplest form, the matching function is defined as: $M_i = m_i(v_i, 1)$, with positive first partial derivatives, negative second derivatives and constant returns to scale. The matching function implies that a firm looking for a worker finds one with probability less than one, equal to $\frac{M_i}{v_i}$, even if there are enough jobs to satisfy all workers. Denoting $\theta_i = \frac{v_i}{L_i}$, the tightness ratio of the labor market, we can rewrite this probability as: $q_i(\theta_i) = \frac{M_i}{v_i} = m_i(1, 1/\theta_i)$. It represents the Poisson matching probability of a vacant job *i-e* the rate at which vacant jobs are filled. Symmetrically, the rate at which an unemployed worker finds a job is given by $\theta_i q_i(\theta_i) = M_i$. Then, for workers in the i area, $\theta_i q_i(\theta_i) L_i = l_i$ of workers are employed in the sector X_i and $[L_i - l_i]$ are unemployed. Thus, if u_i denotes the unemployment rate in region i, the standard Beveridge curve is defined as:

$$u_i = \left[\frac{L_i - \theta_i q_i(\theta_i) L_i}{L_i}\right] = 1 - \theta_i q_i(\theta_i) \tag{2}$$

In the remain of this paper, we will assume for simplicity that [3] :

$q_i(\theta_i) = \frac{M_i}{v_i} = \mu_i \theta_i^{-\xi_i}$, where $0 < \xi_i = -\frac{\partial q(\theta_i)}{\partial \theta_i} * \frac{\theta_i}{q_i(\theta_i)} < 1$ represents the elasticity of the matching function and $\mu_i > 0$ the efficiency of the process.

Consumption preferences

Agents are assumed all risk neutral. Let $C_i^{X_1}$, $C_i^{X_2}$ and C_i^E denote the consumption of regional goods and of the polluting good respectively. They are assumed imperfect substitutes in a composite commodity of quantity $Q = q\left(C_i^E, v(C_i^{X_1}, C_i^{X_2})\right)$.

[3]Pissarides [1998]0, [1986] and Blanchard and Diamond [1989] have shown that a reasonable approximation to the matching function is a Cobb-Douglas function.

We assume functional separability between pollution good and the regional goods in the joint utility function of consumption. Hence, the production function is denoted as $Q = q\left(C_i^E, v(C_i^{X_1}, C_i^{X_2})\right)$ where the first argument of $q(\cdot;\cdot)$ is the polluting good C_i^E and the second argument is the conjoint regional consumption goods $v(C_i^{X_1}, C_i^{X_2})$. This specification is similar to the one used by Copeland and Taylor [2004] and it allows us to solve the model analytically. Functional separation implicitly assumes that the price of the polluting good does not impact the ratio of prices between both regional goods.

In contrast to the standard literature, we do not allow Q to be linearly homogeneous in E. In fact, usual quasi linear and homothetic preferences imply that the elasticity of substitution between polluting goods and regional goods is constant and thus independent on individual revenues. It results in constant expenditures shares of polluting goods. Hence, in most of the models, the revenue of agents does not affect the allocation between clean and dirty goods, and the green tax on the dirty good is superfluous as a distributional device (Jacobs and Van der Ploeg [2010]). However, poor people, but also rural households seem to devote a larger fraction of their consumption to the dirty goods than rich households (Ruiz and Trannoy [2008], Metcalf [1999]). They are therefore the ones most likely to be hurt by an increase in carbon tax. To make the trade-off between redistribution and the efficiency of green tax reforms more realistic and thus more relevant from a policy point of view, we assume Stone-Geary preferences captured by the following consumption utility function Q:

$$Q_i = q\left((C_i^E, v(C_i^{X_1}, C_i^{X_2})\right) = (C_i^E - \bar{E}_i)^{\gamma}\left(v(C_i^{X_1}, C_i^{X_2})\right)^{1-\gamma} \tag{3}$$

$$with \qquad v(C_i^{X_1}, C_i^{X_2}) = \left(C_i^{X_1}\right)^{\sigma}\left(C_i^{X_2}\right)^{1-\sigma} \tag{4}$$

where $\bar{E}_i$ denotes the subsistence level for the polluting good, that differs between regions.

The Stone-Geary utility function makes it possible to model a share of consumption that is not responsive to price changes ($\bar{E}_i$) and another share that can adapt instantaneously to price variations ($C_i^E - \bar{E}_i$). This specification allows us to represent the polluting goods as necessities (their income elasticity is less than unity). Moreover, these elasticities now depend on areas, which captures regional disparities (Deaton and Muellbauer [1980], Chung [1994], Jacobs and van der Ploeg [2010]).

As the environmental degradation acts as an externality, we assume households ignore the adverse effect of their demand for polluting goods on the quality of the environment. Consequently, households i choose $C_i^{X_1}$, $C_i^{X_2}$ and C_i^E in order to maximize utility subject to their budget constraint: $p_1 C_i^{X_1} + C_i^{X_2} + t_E C_i^E = I_i$ (with I_i denoting the income of households i). From the first-order conditions of the maximization of (1), we obtain the uncompensated demand for good $C_i^{X_1}$, $C_i^{X_2}$ and C_i^E and the indirect utility of consumption.

$$C_i^{E*} = \frac{\gamma}{t_E f}\left[I_i - t_E \bar{E}_i\right] + \bar{E}_i$$

$$C_i^{X_1*} = (1-\gamma)\frac{1}{\sigma p_1}\left[I_i - t_E \bar{E}_i\right] = \frac{\sigma p_1}{(1-\sigma)} C_i^{X_2*}$$

$$Q_i^* = \frac{\left[I_i - t_E \bar{E}_i\right]}{P_Q}$$

where P_Q represents the price index defined as : $\left(\frac{t_E}{\gamma}\right)^{\gamma}\left[\frac{(\sigma p_1)^{\sigma}(1-\sigma)^{1-\sigma}}{(1-\gamma)}\right]^{1-\gamma}$.

The consumer first purchases a subsistence level of the polluting good and then allocates the leftover income $\left(I_i - t_E \bar{E}_i\right)$, in fixed proportions to each good according to their respective preference parameter. The assumption of households' risk neutrality implies that their indirect consumption utility is defined as the purchasing power of their leftover income.
Then in this model, households differ with respect to their income (that depends on their sector market activity and on the government transfers), and their consumption commodities tastes depending on their area.

Income and welfare

Workers supply one unit of labor at wage w_i, if employed in sector i. Both unemployed and employed workers receive a same amount of transfers T from national government[4]. The reservation wage, for which a household is indifferent between being employed or unemployed is then driven to zero[5]. Because we consider a static framework of matching, the *ex ante* probability of being unemployed u_i in the areas i, is equal to the *ex post* unemployment rate (Sato [2004]). Assume further that the environmental externality enters the utility function linearly, the indirect utility of workers can be represented by:

$$V_i = u_i * \left[Q_i^*(T)\right] + (1-u_i) * Q_i^*(w_i + T) - \psi\left[E_{tot}\right]$$

where $-\psi\left[E_{tot}\right]$ denotes the disutility due to the environmental degradation, $E_{tot} = E_1 + E_2 + C_1^E + C_2^E$, the aggregated energy demand being the source of global pollution.

[4]We first assume that $T_i = T \ \forall i = 1, 2$. We will remove this assumption in the section 4
.

[5]We could have introduced unemployment benefit and utility of leisure for unemployed worker, that would have defined their reservation wage. But because, in our economy, global prices are equal between regions, there is no reason for different reservation wages between areas. Then, unemployment-benefit modelling becomes superflous.

Denoting from now on the relevant variable of the areas i, with the subscript e or u, depending on whether workers are employed or unemployed, this function can be rewritten as:

$$V_i = u_i * [V_i^u] + (1 - u_i) * V_i^e - \psi [E_{tot}] \tag{5}$$

Migration

As in Harris and Todaro (1970) and many others studies, we assume that workers are perfectly mobile between sectors and areas, and that migration occurs so as to equate the expected indirect utility betwen areas. Then we obtain

$$V_1 = V_2$$

Using (1) and (3), this condition is reduced to:

$$\theta_1 q_1(\theta_1) * [w_1] + V_1^u = \theta_2 q_2(\theta_2) * [w_2] + V_2^u \tag{6}$$

We refer to this condition as the no-migration condition.

2.2 Firm's behavior

Technology

Following Sato [2004], the production in sector X_i consists of f_i many small firms, each of which can employ only one worker. Firms need to post a vacancy in order to hire workers.
Let c_i denotes the exogeneous cost of this vacancy. It can be interpreted as the fixed cost of labor recruitment wich is represented in term of the good X_i. Analogously to Sato [2004], Helsey and Strange [1990] or Montfort and Ottaviano[2000], before paying the cost of posting a vacancy, a firm is not sure to be matched with a worker: remember that due to frictions, a vacant job is matched to an unemployed worker with a probability $q_i(\theta_i) < 1$ [6].
If the job of the firm is occupied, firms demand a polluting factor of production E_i at a price t_E and pay their unique worker a wage w_i. Consequently, the amount of output per firm in the sector i is then: $x_i = F_i(e_i, 1)$ where F_i are concave and display decreasing return to scale with respect to e_i, the demand of polluting good per firm . As in Bovenberg and Van der Ploeg [1998], the aggregate production function amounts to $X_i = l_i x_i = F_i^*(l_i e_i, l_i)$ where F_i^* is concave and features constant returns to scale.

[6] Then $f_i = \frac{l_i}{q_i(\theta_i)} = \theta_i L_i$.

Expected profit of each firm is then:

$$\underset{E_i}{max}\, \pi_i = [q_i(\theta_i)(p_i x_i - w_i - t_E e_i)]\text{-}c_i \text{ s.t. } x_i = F_i\left(e_i, 1\right)$$

The firm's polluting good demand (e_i^*) condition is:

$$p_i \frac{\partial F_i\left(e_i, 1\right)}{\partial e_i} = t_E \tag{7}$$

Denoting α_i the elasticity of the production function x_i with respect to e_i, we can rewrite this condition as:

$$\alpha_i \frac{p_i x_i}{e_i^*} = t_E \tag{8}$$

Assuming free entry of firms, in the steady state, the expected profit from an occupied job equals the expected costs of filling a vacancy, that gives:

$$p_{Li} = p_i x_i - t_E e_i^* = (1 - \alpha_i)\, p_i x_i = w_i + \frac{c_i}{q_i(\theta_i)} \tag{9}$$

Where p_{L_i} denotes the productivity of labor in sector X_i. Equation (6) represents the traditional job creation condition: the marginal cost of investing in a job vacancy must correspond to the expected job rent. In contrast to a competitive labor market where firms hire until marginal productivity is equal to the wage, the total cost of worker exceeds the wage by a recruitment cost.

Wage determination

Once a suitably worker is found, a job rent appears that corresponds to the sum of the expected search and hiring costs for the firm and the worker. Wage needs to share this economic (local-monopoly) rent, in addition to compensating each side for its assets from forming the job. We assume a decentralized Nash bargain, which imposes a particular splitting of the matching surplus between the two parties involved according to the relative bargaining power between them. For a worker, the matching surplus is the difference between its expected utility when employed and that when unemployed: $Q_i^*\left(w_i + T\right) - Q_i^*(T) = \frac{w_i}{P_Q}$. For a firm, the matching surplus is the difference between the profit when it fills a vacancy and when it remains with vacancy: $(p_{L_i} - w_i - c_i) - (c_i) = p_{L_i} - w_i$.

w_i is determined as: $w_i = argmax \left\{ \left(\frac{w_i}{P_Q}\right)^{\beta} (p_{L_i} - w_i)^{1-\beta} \right\}$ with β the worker's bargaining power.

Appendix A.I shows that the first-order condition for the maximization of the Nash product implies the following expression of the wage:

$$w_i = \frac{\beta}{1-\beta} * \left[\frac{c_i}{q_i(\theta_i)}\right] = \beta p_{Li} \tag{10}$$

If hiring costs are zero ($c_i = 0$), in equilibrium $w_i = 0$. Thus, positive hiring costs increase the gap between the utility of employment and that of unemployment. Similary, a drop in job vacancies (or θ_i) decreases the expected value of the firm's hiring costs ($\frac{c_i}{q_i(\theta_i)}$). This reduces the rents from the job match and decreases as well the wage. If the bargaining power of the low-skilled worker equals one (*i-e* $\beta = 1$), then the low-skilled wage equals the productivity of low-skilled labor (similary to competitive labor market), and labor demand doesn't depend at all of hiring costs.

2.3 The government budget constraint

We assume that the government transfers the tax revenue to consumers in a lump-sum fashion.

$$T\bar{L} = t_E E_{tot} \tag{11}$$

2.4 Equilibrium in the good market

Because X_2 is assumed to be the numeraire, we only need to determine the price of X_1.

Following Sato [2004], let Ω be the total left-over income of workers:

$\Omega = (L_1 - l_1)I_1^u + l_1 I_1^e + (L_2 - l_2)I_2^u + l_2 I_2^e - t_E \left(\sum L_i \bar{E}_i\right)$.

The total demand for good X_1 is then :

$\frac{c_1}{q_1(\theta_1)} + (L_1 - l_1)C_{1u}^{X_1} + l_1 C_{1e}^{X_1} + (L_2 - l_2)C_{1u}^{X_1} + l_2 C_{1e}^{X_1} = \frac{c_1}{q_1(\theta_1)} + \left(\frac{1-\gamma}{\sigma p_1}\right)\Omega$
In a symmetrical way, the total demand for good X_2 is given by:

$\frac{c_1}{q_1(\theta_1)} + (L_1 - l_1)C_{1u}^{X_2} + l_1 C_{1e}^{X_2} + (L_2 - l_2)C_{1u}^{X_2} + l_2 C_{1e}^{X_2} = \frac{c_2}{q_2(\theta_2)} + \left(\frac{1-\gamma}{1-\sigma}\right)\Omega$

The equilibrium on good market requires that the total demand equals to the total supply, it means that:

$\frac{c_1}{q_1(\theta_1)} + \left(\frac{1-\gamma}{\sigma p_1}\right)\Omega = x_1 l_1 = X_1$ and $X_2 = l_2 x_2 = \frac{c_2}{q_2(\theta_2)} + \left(\frac{1-\gamma}{1-\sigma}\right)\Omega$

Replacing Ω by the last equation in the total demand of X_2, we found the price of X_1 as follows:

$\frac{p_1}{p_2} = p_1 = \frac{1-\sigma}{\sigma} * \left[\frac{x_2 l_2 - \frac{c_2}{q(\theta_2)}}{x_1 l_1 - \frac{c_1}{q(\theta_1)}}\right]$

Noticing with equation (10) that $\frac{c_i}{q_i(\theta_i)} = \left[\frac{1-\beta}{\beta}\right] w_i$, it gives :

$$p_1 = \frac{1-\sigma}{\sigma} * \left[\frac{l_2\left(F_2(e_2,1) - \left[\frac{1-\beta}{\beta}\right] w_2\right)}{l_1\left(F_1(e_1,1) - \left[\frac{1-\beta}{\beta}\right] w_1\right)}\right] \tag{12}$$

3 General Equilibrium

We define the equilibrium of the model as a tuple (L_i^*, l_i^*, e_i*, θ_i^*, w_i^*, p_i^*) for $i = 1, 2$, of 6*2 variables that satisfies the following conditions: the job creation conditions (9), the wage mark up equations (10), the Beveridge curves (2), the firms' energy demands (7) , the no-migration condition (6), the total labour endowment equation (1), the price equation (12) and the price normalization $p_1 = 1$, that we will call (C1). Assuming an explicit form for $F_i(e_i, 1) = e_i^{\alpha_i}$, allows us to solve the model in level.

From (C1), (9) and (10), (7) yields the equilibrium demand of polluting good from the sector 2:

$$e_2^* = \left[\frac{\alpha_2}{t_E}\right]^{\frac{1}{1-\alpha_2}} \tag{13}$$

And remembering that $p_{L_2} = (1-\alpha_2)\, p_2 x_2$, we have:

$$p^*_{L_2} = (1-\alpha_2) \left[\frac{\alpha_2}{t_E}\right]^{\frac{\alpha_2}{1-\alpha_2}} \tag{14}$$

As pollution is used as input, it is not surprising to obtain the productivity of labor in region 2 as a decreasing function with respect to t_E .

Substituting $p^*_{L_2}$ into (10) gives the equilibrium probability for a firm to find a worker $q(\theta^*_2)$ and the equilibrium wage w^*_2 that amounts to:

$$q(\theta^*_2) = \frac{c_2}{(1-\beta)p_{L2}} = \frac{c_2}{(1-\beta)\,(1-\alpha_2)} \left[\frac{\alpha_2}{t_E}\right]^{\frac{-\alpha_2}{1-\alpha_2}} \tag{15}$$

$$w^*_2 = \beta p^*_{L_2} = \beta\,(1-\alpha_2) \left[\frac{\alpha_2}{t_E}\right]^{\frac{\alpha_2}{1-\alpha_2}} \tag{16}$$

The probability of finding a worker for a firm in region 2 is increasing with the pollution tax. Intuitively, increasing pollution tax, because it increases the factor prices, lowers the profit of a functional firm (with a job filled). Because, in the long run, the expected profit is always equivalent to the expected costs of opening a vacancy that is fixed, the zero profit condition leads to an increase $q_2(\theta^*_2)$. Symmetrically, a pollution tax lowers the probability for a worker to find a job in the area 2, and decreases also its wage.

From the migration condition and with (10), we finally find θ^*_1 in function of θ^*_2:

$$\theta^*_1 = \frac{c_2}{c_1}\theta^*_2 + P_Q \frac{1-\beta}{\beta} \left(V^u_2 - V^u_1\right) \tag{17}$$

Remember that $P_Q \frac{1-\beta}{\beta} \left(V^u_2 - V^u_1\right) = t_E \frac{1-\beta}{\beta} \left(\bar{E}_1 - \bar{E}_2\right)$. Equation (17) shows that if the subsistence levels of pollution were the same in both areas, $(\bar{E}_1 = \bar{E}_2)$, the no-migration condition should require that $\theta^*_1 = \frac{c_2}{c_1}\theta^*_2$, that means that the ratio of frictions should be equal to the ratio of the vacancy costs. Thus, the non-homothetic preferences assumption, implies that the substistence level of energy consumption enters directly in the arbitrage of location choice of the agents.

Substituting θ^*_1 into (7), (10) and (9), gives the equilibrium wage of region 1:

$$w_1^* = \left[\frac{\beta}{1-\beta}\frac{c_1}{q_1(\theta_1^*)}\right] \tag{18}$$

If $\forall i = 1,2,\ \bar{E}_i = \bar{E}$, we would have obtained $\theta_1^* = \frac{c_2}{c_1}\theta_2^*$. In this case, with w_1^* and w_2^*, we obtain: $\frac{w_1^*}{w_2^*} = \frac{c_1 q(\theta_2^*)}{c_2 q(\theta_1^*)} = \left(\frac{c_1}{c_2}\right)^{1+\xi_1} \theta_2^{*\xi_1-\xi_2}\frac{\mu_2}{\mu_1}$: the only wage disparity between regions would have been driven by differences of efficiency in the matching functions, weighted by the ratio of the cost vancancies $\frac{w_1^*}{w_2^*} = \frac{c_1 q(\theta_2^*)}{c_2 q(\theta_1^*)}$. But, it is interesting to notice that here, because of the non-homothetic utility assumption, the difference in the subsistence level of the dirty good consumption implies necessarly a wage disparity that amplifies frictions in the region where its is the largest ($\theta_1^* = \frac{c_2}{c_1}\theta_2^* + \frac{1-\beta}{\beta}\left(t_E\frac{1-\beta}{\beta}\left(\bar{E_1} - \bar{E_2}\right)\right)$. We should have a clear understanding of these two distinct labor market distortions. The difference in subsistence level of production should be interpreted as an additional labor distortion. In other words, the no-migration condition, driven by wage disparities, causes an additional misallocation of labor between the two regions.

Proposition 1: *The model has a unique equilibrium, which is characterized by an inter-sector wage disparity due to frictions in forming jobs and to the difference between regional subsistence levels of the pollution good. With a higher pollution tax, the sector presenting the highest frictional unemployment generates the highest wage.* $\left(\frac{w_1^*}{w_2^*} = \frac{c_1 q(\theta_2^*)}{c_2 q(\theta_1^*)}\right)$. *Frictions are amplified if the highest initial labor market frictions is in the area where the subsistence level of the polluting good is also the highest.*

Substituting w_1^* into (10) and (9), we obtain:

$$e_1^* = \left[\frac{\alpha_1}{t_E} * \frac{c_1}{q_1(\theta_1^*)}\frac{1}{1-\alpha_1}\right] \tag{19}$$

$$p_1^* = \left[\left(\frac{\alpha_1}{t_E}\right)^{-\alpha_1} * \left(\frac{c_1}{q_1(\theta_1^*)}\frac{1}{1-\alpha_1}\right)^{1-\alpha_1}\right] \tag{20}$$

By noting that $\theta{*}_1 = \frac{c_2}{c_1}\theta_2^* + t_E\frac{1-\beta}{\beta}\left(\bar{E_1} - \bar{E_2}\right)$, we obtain

$p_1^* = \left[\left(\frac{t_E}{\alpha_1}\right)^{\alpha_1} * q(\theta_1^*)^{-(1-\alpha_1)}\left(\frac{c_1}{1-\alpha_1}\right)^{1-\alpha_1}\right]$

$\Longleftrightarrow$

$$p_1^* = \left[\left(\frac{t_E}{\alpha_1}\right)^{\alpha_1} * \frac{\mu_1}{\mu_2} \left[\left(\frac{c_2\mu_2}{(1-\beta)(1-\alpha_2)} \left[\frac{t_E}{\alpha_2}\right] \right)^{\frac{\alpha_2-(1-\alpha_2)\xi_2}{(1-\alpha_2)\xi_2}} + t_E \frac{1-\beta}{\beta} \left(\bar{E_1} - \bar{E_2}\right) \right]^{(1-\alpha_1)\xi_1} \left(\frac{c_1}{1-\alpha_1}\right)^{1-\alpha_1} \right]$$

Appendix (A.II) gives the sign of the derivative of p_1^* with respect to the pollution tax. We proof that $\frac{dp_1^*}{dt_E} > 0$ if and only if:

$$t_E < \left[\frac{c_2\mu_2}{(1-\beta)(1-\alpha_2)}\right]^{\gamma_1} \left[\frac{\gamma_1}{\gamma_3\gamma_2-\gamma_1}\left(\bar{E_1} - \bar{E_2}\right)\right] = \bar{\tau}$$

With: $\gamma_1 = \alpha_1 + (1-\alpha_1)\xi_1$; $\gamma_2 = \frac{\alpha_2-(1-\alpha_2)\xi_2}{(1-\alpha_2)\xi_2}$ and $\gamma_3 = (1-\alpha_1)\xi_1$

Note that if $\bar{E_1} - \bar{E_2} = 0$, a sufficient condition is:
$\frac{\gamma_1}{t_E} - (\gamma_3\gamma_2)\frac{a[t_E]^{-\gamma_2-1}}{a[t_E]^{-\gamma_2}} > 0,$
$\Longleftrightarrow$
$\frac{\alpha_1}{1-\alpha_1}\frac{1}{\xi_1} > \frac{1}{\xi_2}\frac{\alpha_2}{1-\alpha_2}$

Proposition 2 sumumarizes the above arguments :

Proposition 2: *In the case where $\bar{E_1} = \bar{E_2}$, the relative price of goods (p_1^*) is a decreasing function of the green tax rate if and only if the ratio of the he elasticity of the production function with respect to energy over the elasticity of the matching fonction is higher in the sector X_1 than in the sector X_2intensive in pollution ($\frac{1}{\xi_1}\frac{\alpha_1}{1-\alpha_1} > \frac{1}{\xi_2}\frac{\alpha_2}{1-\alpha_2}$).*
In the case where $\left(\bar{E_1} > \bar{E_2}\right)$, the sign of the derivatives $\frac{dp_1^*}{dt_e}$ is ambiguous. There exists a threshold $\bar{\tau}$, such that if $t_e > \bar{\tau}$ then p_{*1} increases with t_E . The threshold is an increasing function of the difference in the subsistence level $\left(\bar{E_1} - \bar{E_2}\right)$.

In the case where $\bar{E_1} = \bar{E_2}$, p_1^* increases with t_E only if ($\frac{1}{\xi_1}\frac{\alpha_1}{1-\alpha_1} > \frac{1}{\xi_2}\frac{\alpha_2}{1-\alpha_2}$). This results is really intuitive: both production sectors use pollution, the relative price of goods thus depend explicitly of their relative intensity. This is what we can call the *pollution-intensity effect*. Finally, the productivity of labor in the the less intensive sector will increase compared to the other, that leads to a wage disparity in favor of the less energy-intensive sector. The same reasoning can be apply for the elasticity of the macting function, that characterizes the frictions.
Again, the non-homothetic preferences generate ambiguity, because frictions, through the migration condition, depend on the difference between substitute levels. Suppose ($\frac{\alpha_1}{1-\alpha_1} > \frac{\alpha_2}{1-\alpha_2}$) that means that the sector 1 is the more energy intensive. It is possible that if $\bar{E_2} - \bar{E_1}$ is large

enough, that the price of p_1 decreases, because the wage disparity induced by the *pollution-intensity effect* is not enough to overcome the loss on the purchase power of the agents in the area 2. Then, the non migration condition requires that the wage of the firm in 2 has to increase more. Leading to a decrease of p_1^* (this is the loss of purchasing power).

We can rewrite the migration condition, noting that $\theta_1 q(\theta_1) = \frac{l_1}{L_1}$ and substituting (10) into (11), we finally obtain:

$$\frac{L - L_1}{L_1} = \frac{L_2}{L_1} = \frac{[1-(1-\alpha_1)(1-\beta)p_1^*]}{[1-(1-\alpha_2)(1-\beta)]} * \frac{\sigma}{1-\sigma} * \frac{w_2^* + P_Q \frac{1-\beta}{\beta}(V_2^u - V_1^u)}{w_2^*} \tag{21}$$

Solving for L_1^* we find that:

$\frac{L_2^*}{L_1^*} > 1 \iff$

$$t_E < \left[\left((1-\alpha_2)^{\xi_1} \alpha_1^{\frac{\alpha_2 \xi_2}{1-\alpha_2}} \frac{1-\beta}{\xi_2} \right)^{-(1-\beta)} \left(\frac{1-(1-\alpha_2)(1-\beta)}{(1-\alpha_1)(1-\beta)} \left(1 + \frac{\sigma}{1-\sigma} \left[\bar{E_1} - \bar{E_2} \right] \right) \right) \right]^{\left(\alpha_1(1-\alpha_2) - \alpha_2(1-\alpha_1)\frac{\mu 2}{\mu_1} \right)}$$

The sign of inequality must be reversed if $\frac{1}{\xi_1}\frac{\alpha_1}{1-\alpha_1} < \frac{1}{\xi_2}\frac{\alpha_2}{1-\alpha_2}$ (that means that the ratio of pollution intensity between sectors is lower than the ratio of frictions bewteen sectors).

If the pollution intensity and the frictions in sector 1 are low enough compared to the one of the sector 2, than there exist :

$$\bar{\tau}' = \left[\left((1-\alpha_2)^{\xi_1} \alpha_1^{\frac{\alpha_2 \xi_2}{1-\alpha_2}} \frac{1-\beta}{\xi_2} \right)^{-\xi(1-\beta)} \left(\frac{1-(1-\alpha_2)(1-\beta)}{(1-\alpha_1)(1-\beta)} \left(1 + \frac{\sigma}{1-\sigma} \left[\bar{E_1} - \bar{E_2} \right] \right) \right) \right]^{\left(\alpha_1(1-\alpha_2) - \alpha_2(1-\alpha_1)\frac{\mu 2}{\mu_1} \right)}$$

such that if $t_E < \bar{\tau}'$ then $\frac{L_2}{L_1} > 1$

Proposition 3: *If* $\left(\bar{E_1} - \bar{E_2} > 0\right)$, *and if the area 1, presenting the lowest frictional unemployment is also the less pollution intensive (i-e* $\left(\frac{1}{\xi_1}\frac{\alpha_1}{1-\alpha_1} < \frac{1}{\xi_2}\frac{\alpha_2}{1-\alpha_2}\right)$*holds), the initial number of workers in the area 1 is lower that those in the area two 1 if and only if* $t_E < \bar{\tau}'$ *.*

Corollary : *If* $\left(\bar{E_1} - \bar{E_2} > 0\right)$ *, the sector presenting the lowest frictional unemployment is also the less pollution intensive (i-e*$\left(\frac{1}{\xi_1}\frac{\alpha_1}{1-\alpha_1} < \frac{1}{\xi_2}\frac{\alpha_2}{1-\alpha_2}\right)$ *holds) and the initial green tax lies in the lower range* $t_E \in [\tau, \tau']$*, then the migration induced by an increase of green taxes contributes to improve the economic welfare. Else, green taxes exacerbate existing spillovers.*

(see the proof in Appendix)

In that case, an increase in the environmental tax rate decreases the ratio of prices of the economy (p_1*) and population migrates into the area 1, that is into the lowest frictional and the less energy intensive. Migration in this case, contributes to bring the economy closer from the optimal location of agents.

4 Welfare effects of taxation and inter-region transfers

Having examined the distributional effects of the imposition of a corrective tax, it is worth examining the total welfare effect of this tax.
The Benthamite social welfare function gives us:

$$W = \sum_{i=1}^{2} \left[(L_i - l_i) * V_i^u + l_i * V_i^e\right] - \bar{L}\psi\left[E_{tot}\right]$$

Because in this paper, we do not allow for heterogeneous valuations of damages from pollution and we consider separable utility functions, it is here possible to distinguish an environmental component and a non-environmental one (as in Bovenberg and de Mooij [1994])
Then, our economic efficiency criterion in this paper, the non-environmental component W^{NE} only considers :

$$W^{NE} = \sum_{i=1}^{2} \left[(L_i - l_i) * V_i^u + l_i * V_i^e\right]$$

Using (1), the no-migration condition (6) and the government budget constraint (11) , we can rewrite this economic part of the social welfare as:

$$W^{NE} = \frac{\bar{L}\left(\theta_2 q(\theta_2) w_2 - t_E \bar{E_2}\right) + \bar{L}T}{P_Q}$$

with $T = \frac{t_E E_{Tot}}{L}$

In some case, by exacerbing frictions in the total economie, environmental tax may exerce a spillover that can be lowered by an appropriate reallocation of agents in the economie. We propose in this paper to use different transfer T_i in the design of the environmental tax reform. Consequently, we allow dT_1 to differ from dT_2 in the following way:
$dT_2 = \lambda dT$

The governement constraint (11) holds, it gives us:

$d(T_1 - T_2) = (1 - \lambda)\, \frac{LdT}{L_1}$

(note that we differentiate the equation at equilibrium where $(T_1 - T_2 = 0)$)

Where $0 < \lambda < 1$ represents the policy index of the reform: If $\lambda = 1$, then $dT_1 = dT_2 = dT$, if $\lambda = 0$, we redistribute everything to the agents of the region 1.

Because $d\theta_2$, dw_2^* and de_2^* do not depend on $d(T_2 - T_1)$, we can write the following expression:

$$\triangle = \frac{dW^{NE}}{dt_E}(d(T_1 - T_2) > 0) - \frac{dW^{NE}}{dt_E}(d(T_1 - T_2) = 0) > 0 \iff$$

$$\iff \left(\frac{dP_Q(\lambda = 1)}{dt_E}\frac{1}{P_Q} - \frac{dP_Q(\lambda < 1)}{dt_E}\frac{1}{P_Q}\right) > (dT - dT_2)$$

The previous equation shows that, in order to improve the welfare, the difference in transfers between a situation where $\lambda = 1$, and $\lambda < 1$, has to be bigger than the loss in term purchase power induced by this change.

if $[dT_1 - dT_2]>0$

$$\iff \left[(\sigma)(1-\gamma)(1-\alpha_1)\,\xi\left[\left(\frac{1-\beta}{\beta c_1\theta_1^*}\right)\right]\right] > \frac{[dT - dT_2]}{[dT_1 - dT_2]}$$

And with the differentiate of the government budget constraint we obtain:

$$\iff \left[(\gamma)(1-\sigma)(1-\alpha_1)\,\xi\left[\left(\frac{1-\beta}{\beta c_1}\right)\right]\right] > \frac{[L_1^*\theta_1^*]}{[L]}$$

Appendix A.III gives the details of the computation.

Proposition 4 *: It is efficient to redistribute form region 2 to region 1 ($\lambda < 1$) if and only if* $\left[(\gamma)(1-\sigma)(1-\alpha_1)\,\xi\left[\left(\frac{1-\beta}{\beta c_1}\right)\right]\right] > \frac{[L_1^*\theta_1^*]}{[L]}$. *That means that the initial friction and the initial population in the region 1 must not be too high.*

5 Conclusion

This paper aims to investigate the local dimension in the regressivity of green taxes. Based on the Harris-Todaro framework, our model contains several features that contribute to better understand the distribution of green taxes burden from the perspective of regional inequalities. In contrast to the previous studies in Harris-Todaro framework, pollution is due to the use of a dirty input in both production processes, that can be also consumed by household. Commodities tastes differ among areas and we assume non-homothetic preferences for the polluting good consumption. It allows us to represent the dirty goods as necessities. Finally, we introduced frictional unemployment in both sectors. Thus, we allow regions/areas to differ with respect to three components: (i) the subsistence level of the dirty consumption of their residents, (ii) the pollution intensity of their production sector, and (iii) the level of frictions on their labor market.

We show that if the sector presenting the lowest frictional unemployment is also the less pollution intensive and the initial green tax lies in the lower range, then the migration may contribute to improve the welfare. Yet, the difference in subsistence level of the polluting good among regions exacerbate the sector-wage disparities due to frictions and generates spillovers. We finally identify conditions under which the reform can be made pareto improving by allowing different lump-sum transfers for regions.

This paper is still in progress and we intend to complement it with further investigations. First, we did not analyzed the environmental implication of the increase of a green tax yet. Because, all goods are polluting or produce with pollution, it is quite obvious that the first dividend will be obtained, even if the migration limites spillovers. But it would be interesting to analyse the trade-off between the efficiency objective of the governement and the environmnental one. Moroever, if the strong form of the double dividend can not be obtained in this framework, the weak one is still possible (Daitoh [2004]). Finally, simulations will be usefull to highlight the room for manoeuvre for environmental tax reforms in function to the initial tax system.

Appendix

A.I : Wage bargaigning

Wage of worker_i is determined as: $w_L = argmax\left\{\left(Q_i^*\left(I_i^E\right) - Q(I_i^U)\right)^{\beta}\left(p_{Li} - w_L\right)^{1-\beta}\right\}$

where $Q^*\left(I_i^E\right) = \left(\frac{w_i + T_i - t_E\bar{E}_i}{P_Q}\right)$ and $\left[Q^*(I_i^U)\right] = \left(\frac{T_i - t_E\bar{E}_i}{P_Q}\right)$

This is equivalent to $w_L = argmax\left\{\beta\left(lnQ^*\left(I_i^E\right) - \left[Q^*(I_i^U)\right]\right) + (1-\beta)ln\left(p_{Li} - w_L\right)\right\}$. First order condition gives: $\beta\left[\frac{1}{P_Q\left[Q_i^{E*} - Q_i^{U*}\right]}\right] - (1-\beta)\left[\frac{1}{p_{L_i} - w_L}\right] = 0$. And with equation (7) we obtain:

$P_Q\left[Q_i^{E*} - Q_i^{U*}\right] = w_i = \frac{\beta}{1-\beta} * \left[p_{L_i} - w_{Li}\right] = \frac{\beta}{1-\beta} * \left[\frac{c}{q(\theta)}\right]$ (A.1)

A.II : the derivatives of $p_1^*$with respect to the green taxe

$$p_1^* = \left[\left(\frac{(1+t_E)p_E}{\alpha_1}\right)^{\alpha_1} * \frac{\mu_1}{\mu_2}\left[\left(\frac{c_2\mu_2}{(1-\beta)(1-\alpha_2)}\left[\frac{(1+t_E)p_E}{\alpha_2}\right]\right)^{\frac{\alpha_2-(1-\alpha_2)\xi}{(1-\alpha_2)\xi}} + (1+t_E)\,p_E\frac{1-\beta}{\beta}\left(\bar{E}_1 - \bar{E}_2\right)\right]^{(1-\alpha_1)\xi}\left(\frac{c_1}{1-\alpha_1}\right)^{1-\alpha_1}\right]$$

$$\iff \frac{dp_1^*}{dt_E} = p_1^*\left[\frac{\gamma_1}{t_E} - (\gamma_3\gamma_2)\frac{a[t_E]^{-\gamma_2-1}}{a[t_E]^{-\gamma_2} + \frac{1-\beta}{\beta}\left(\bar{E}_1 - \bar{E}_2\right)}\right]$$

$with\ \gamma_1 = \alpha_1 + (1-\alpha_1)\xi\ ;\ \gamma_2 = \frac{\alpha_2-(1-\alpha_2)\xi}{(1-\alpha_2)\xi}\ and\ \gamma_3 = \frac{(1-\alpha_1)\xi}{(1-\alpha_2)\xi}$

Then we have: $\frac{dp_1^*}{dt_E} > 0$ if and only if:

$$\frac{\gamma_1}{t_E} - (\gamma_3\gamma_2)\frac{a[t_E]^{-\gamma_2-1}}{a[t_E]^{-\gamma_2} + \frac{1-\beta}{\beta}\left(\bar{E}_1 - \bar{E}_2\right)} > 0$$

$$\iff t_E < \left[\frac{c_2\mu_2}{(1-\beta)(1-\alpha_2)}\right]_E^{\gamma_1}\left[\frac{\gamma_1}{\gamma_3\gamma_2 - \gamma_1}\left(\bar{E}_1 - \bar{E}_2\right)\right] = \bar{\tau}$$

Note that if $\left(\bar{E}_1 - \bar{E}_2\right) = 0$, a sufficient condition is:
$\frac{\gamma_1}{t_E} - (\gamma_3\gamma_2)\frac{a[t_E]^{-\gamma_2-1}}{a[t_E]^{-\gamma_2}} > 0$,
$\iff$
$\frac{\alpha_1}{1-\alpha_1} > \frac{\alpha_2}{1-\alpha_2}$

A.III : inter-regional transfers

We have:

$$\triangle = \frac{dW^{NE}}{dt_E}(d(T_1 - T_2) > 0) - \frac{dW^{NE}}{dt_E}(d(T_1 - T_2) = 0) > 0 \iff$$

$$\iff \left(\frac{dP_Q(\lambda = 0)}{dt_E}\frac{1}{P_Q} - \frac{dP_Q(\lambda > 0)}{dt_E}\frac{1}{P_Q}\right) > dT - dT_2$$

And with the derivatives of $P_Q = \left(\frac{t_E}{\gamma}\right)^{\gamma}\left[\frac{(\sigma p_1)^{\sigma}(1-\sigma)^{1-\sigma}}{(1-\gamma)}\right]^{1-\gamma}$

We find that $\tilde{P_Q} = \gamma\frac{dt_E}{t_E} + (\sigma)(1-\gamma)\tilde{p}_1$

Or $\tilde{p}_1 = \alpha\frac{dt_E}{t_E} + (1-\alpha_1)\xi\tilde{\theta_1}$

Then, $\tilde{\theta_1}(\lambda = 0) - \tilde{\theta_1}(\lambda = 0)(\lambda > 0) = \left(\frac{1-\beta}{\beta c_1 \theta_1^*}\right)[dT_1 - dT_2]$

Finally we obtain:

$$\left(\frac{dP_Q(\lambda = 0)}{dt_E}\frac{1}{P_Q} - \frac{dP_Q(\lambda > 0)}{dt_E}\frac{1}{P_Q}\right) > dT - dT_2$$

$$\iff \left[(\sigma)(1-\gamma)(1-\alpha_1)\xi\left[\left(\frac{1-\beta}{\beta c_1 \theta_1^*}\right)\right]\right][dT_1 - dT_2] > [dT - dT_2]$$

if $[dT_1 - dT_2]{>}0$

$$\iff \left[(\sigma)(1-\gamma)(1-\alpha_1)\xi\left[\left(\frac{1-\beta}{\beta c_1 \theta_1^*}\right)\right]\right] > \frac{[dT - dT_2]}{[dT_1 - dT_2]}$$

$$\iff \left[(\sigma)(1-\gamma)(1-\alpha_1)\xi\left[\left(\frac{1-\beta}{\beta c_1 \theta_1^*}\right)\right]\right] > \frac{[(1-\lambda)\,dT]}{\left[(1-\lambda)\,\frac{LdT}{L_1}\right]}$$

$$\iff \left[(\gamma)(1-\sigma)(1-\alpha_1)\xi\left[\left(\frac{1-\beta}{\beta c_1 \theta_1^*}\right)\right]\right] > \frac{[L_1^*]}{[L]}$$

$$\iff \left[(\gamma)(1-\sigma)(1-\alpha_1)\xi\left[\left(\frac{1-\beta}{\beta c_1}\right)\right]\right] > \frac{[L_1^*\theta_1^*]}{[L]}$$

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