The Tradeoff Between Employment and Environment

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Abstract

Many believe that climate-change policies trade off employment for the environment. Can't we have it both? We construct a search-equilibrium model to answer the question. We show that under relatively mild assumptions, the introduction of a large class of climate-change policy combats emission and employment. While many nations implemented these policies, we show that adjusting the preexisting emission tax rate or intensity standard cannot avoid the employment-environment tradeoff. However, there always exist intensity standards such that a policy shift from a preexisting emission tax to the intensity standard improves the natural and business environments, not vice versa. This paper raises concern on the political feasibility of climate-change policies, uncovers major mechanisms driving the employment-environment tradeoff, and provides guidance on policy formulation.

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1 Introduction

Climate change has received an increasing attention from the international community, calling for policies to improve the natural environment. Despite the call for climate-change policies, economists and scientists have not captured all its ramifications. Among others, prior literature (Greenstone, 2002; Walker, 2011; Kahn and Mansur, 2013) documents that climate-change policies create substantial job losses in regulated sectors. Meanwhile, Yip (2018, 2021) find that a climate-change policy could increase the unemployment rate by over two percentage points. Such a significant unemployment effect may have raised public concerns on the labor market consequences of climate-change policies, undermining its political feasibility.

After all, is the employment-environment tradeoff inevitable? To answer the question, this paper provides an in-depth analysis on the labor market consequences of climate-change policies. If the tradeoff is avoidable, why is the public so concerned with climate-change legislation? If the tradeoff is inevitable, what is the fundamental economic reason driving the tradeoff? While many nations may have a preexisting climate-change policy, such as an emission tax and an intensity standard, could we improve the natural and business environments simply by adjusting the preexisting emission tax rate or intensity standard? Could we replace a preexisting emission tax with an intensity standard to simultaneously enhance the employment opportunity and environmental quality? Could we substitute an emission tax rate for a preexisting intensity standard to achieve the two goals? This paper will answer these questions.

Answering these questions are informative for at least three reasons. First, it addresses the public concern on labor market responses to climate-change policies. Moreover, it helps economists understand the interaction between the employment and environmental problems, revealing major channels through which the employment-environment tradeoff operates. Furthermore, it helps policymakers with the formulation of climate-change policies, avoiding its ramifications and enhancing its political feasibility.

We bring an economic theory to answer the questions. We incorporate emission decisions along extensive and intensive margins into a two-sector search equilibrium model (Acemoglu, 2001; Chassamboulli and Palivos, 2014). Real labor markets are imperfect. Frictions and externalities prevent instant market clearing, creating involuntary unemployment. While Hafstead et al. (2018) finds it important to incorporate search friction into a model to evaluate the unemployment effect of climate-change policies, Yip (2018) finds the involuntary unemployment effect of a climate-change policy significant. Hence, we consider search friction and congestion externality to capture such an involuntary unemployment effect in our analysis.

Moreover, our model features multiple sectors. While the literature documents significant job losses created by climate-change policies (Greenstone, 2002; Walker, 2011; Kahn and Mansur, 2013; Yamazaki, 2017), recent literature argues that sectoral reallocation may absorb unemployment (Hafstead and Williams, 2018; Castellanos and Heutel, 2019), making the overall unemployment effect ambiguous. The integration of multiple sectors allows our model to capture sectoral reallocation to evaluate the overall unemployment effect.

Furthermore, our model allows emissions to be adjusted along both intensive and extensive margins. Earlier literature assumes the intensive margin of emission to be fixed (Carraro et al., 1996; Bye, 2002), which can be interpreted as a short-term technological constraint. However, this margin is found to play an important role for controlling emission in practice (Shapiro and Walker, 2018). Meanwhile, the extensive margin is the driving force for job losses upon the introduction of climate-change policies (Walker, 2011). Therefore, to endogenize the two margins allows our model to provide a comprehensive review of the tradeoff between the employment opportunity and environmental quality.

As such, our simple but intuitive model captures frictional unemployment, sectoral reallocation, emission along both margins, etc., all of which are important to the problem at hand. These features allow us to explore concrete policy issues for which our analysis can be applied. Given its stylized nature and analytical tractability, our model sheds light on the employment-environment tradeoff by uncovering key mechanisms at play.

We find that a large class of climate-change policies increases unemployment. This class of policies shares a common feature: it increases flow cost in polluting sectors without subsidizing nonpolluting sectors. The increased cost, such as a lump-sum tax, an emission tax payment, an abatement cost, etc., reduces flow profits. This primary effect leads the polluting sector to create fewer jobs, worsening unemployment. While unemployed workers become relatively more abundant, they are willing to work with a lower wage. Taking the advantage of the lower labor cost, the nonpolluting sector generates higher profits. This general equilibrium effect leads the nonpolluting sector to create more jobs, absorbing unemployment. Under mild assumptions, we show that the sectoral reallocation can ease but cannot eliminate the unemployment effect. This finding suggests that we can't have it both ways—a large class of popular climate-change policies will combat emission and employment, partly explaining why the public is so concerned with the job losses created by climate-change policies.

We also explore policy scenarios in which the economy has a preexisting climate-change policy. We find that simply adjusting the preexisting emission tax rate or intensity standard cannot break the employment-environment tradeoff—the adjustments either cut emissions or jobs. We further show that an emission tax is inferior to an intensity standard in the labor market. Given any emission tax rate, there always exists a wide range of intensity standards with better employment opportunities and environmental qualities than the preexisting emission tax policy. However, given any intensity standard, there exists no such an emission tax rate that can break the employment-environment tradeoff. In other words, it is possible to simultaneously improve the employment opportunity and environmental quality simply by substituting an appropriate intensity standard for the preexisting emission tax policy, not vice versa.

The superiority of intensity standards over emission taxes arises from cost differentials. To achieve the same abatement level, a firm is required to pay the same amount of abatement cost under the two policies. While an emission tax policy incurs both the abatement cost and emission tax payment, a firm is only required to pay the abatement cost under an intensity standard. As such, an emission tax incurs a higher flow cost than an intensity standard. The cost differential allows an intensity standard to abate emissions without losing as many jobs as an emission tax policy does.

This paper contributes to the literature that studies the labor market consequences of climate-change policies. Many empirical studies document significant employment losses associated with climate-change policies in regulated sectors (Greenstone, 2002; Walker, 2011; Kahn and Mansur, 2013; Carbone et al., 2020). However, recent literature argues that climate-change policies may shift employment from regulated sectors to unregulated ones (Hafstead and Williams, 2018; Castellanos and Heutel, 2019) and may create green jobs (Wagner, 2005; Vona et al., 2018; Marin and Vona, 2019), both of which absorb unemployment and make the overall unemployment effect of climate-change policies ambiguous.

Having considered the two channels, Yip (2018, 2021) finds that the unemployment effect of a revenue-neutral emission tax remains significant. Ferris et al. (2014) and Yip (2021) provide evidence that the significant (un)employment effects of climate-change policies are short-lived, partly explaining why the literature may find little evidence on the significant unemployment effect of climate-change policies over a prolonged post-policy period. Meanwhile, they recognize the public concern on employment losses associated with climate-change policies. This paper speaks to this empirical literature by uncovering the mechanisms through which a wide range of climate-change polices affects the labor market, by explaining why the public is so concerned with climate-change legislation, and by revealing essential features of climate-change policies that help break the employment-environment tradeoff.

Moreover, this paper complements quantitative analyses in this literature. Hafstead et al. (2018) and Hafstead and Williams (2018) calibrate a search-computable general equilibrium model to the US economy and find that the unemployment effects of various climate-change policies are weak. We construct a simpler analytically tractable search-equilibrium model to shed light on the mechanisms through which the unemployment effect of climate-change policies operates. Hence, this paper and the two recent studies combine the strengths of analytical and numerical approaches: while our stylized analytical model uncovers major mechanisms at play, their numerical models measure the empirical significance of these mechanisms.

This paper also contributes to the analytical work that studies the unemployment effect of climate-change policies. A series of influential papers by Bovenberg and van der Ploeg studies the impacts of emission taxes on the labor market (Bovenberg and van der Ploeg, 1996, 1998a,b). Aubert and Chiroleu-Assouline (2017) studies the efficiency consequences of an emission tax in a search-equilibrium framework. In contrast to these studies, our paper simultaneously considers search friction, sectoral reallocation, emissions along two margins, price effects etc., all of which are considered to be important in understanding the labor market effects of climate-change policies (Carraro et al., 1996; Bye, 2002; Walker, 2011; Yamazaki, 2017; Hafstead et al., 2018; Hafstead and Williams, 2018; Shapiro and Walker, 2018; Carbone et al., 2020). These features jointly make our work unique in this literature.

Moreover, this paper deals with policy issues that have not received much attention in previous formal analytical work. While much effort is devoted to the unemployment effect of emission taxes in prior studies, this paper considers a wide range of climate-change policies, including intensity standards and emission taxes. Furthermore, prior analytical work examines cases in which an economy introduces a climate-change policy in the absence of a preexisting climate-change policy. Nevertheless, many nations, both developed and developing ones, have a preexisting climate-change policy. This paper brings an economic theory to analytically examine policy scenarios in which an economy replaces the preexisting climate-change policy with another policy.

This paper also speaks to the literature on the comparison between emission taxes and intensity standards in different contexts. While taxes are often considered first-best, Tombe and Winter (2015) highlights that *"a number of factors favor intensity standards: market power (Li and Shi, 2011), incomplete regulation (Holland, 2012), learning-by-doing in production (Gerlagh and Van der Zwaan, 2006), pre-existing tax distortions (Parry and Williams, 2012), and unexpected productivity shocks (Fischer and Springborn, 2011)"*, etc. This paper contributes to the literature by providing a formal proof of the superiority of intensity standards over emission taxes in terms of the employment-environment tradeoff. Our finding provides an additional rationale explaining why intensity standards could be preferred to emission taxes in the labor market.

Before closing this section, it is worth highlighting that our model by no means exhaustively captures all possible channels through which climate-change policies affect labor market activities. It calls for attention to the key mechanisms resulting in the employment-environment tradeoff in climate-change policy formulation.

The rest of the paper is organized as follows. Section 2 presents the structure of the model. Section 3 analyzes the employment-environment tradeoff in the policy scenario in which a climate-change policy is introduced to an economy with no preexisting climate-change policy. Section 4 analyzes the policy scenario in which a climate-change policy is replaced by another one. Section 5 concludes the paper.

2 The Basic Model

This section constructs a simple search-equilibrium model to shed light on the tradeoff between the employment opportunity (i.e., frictional unemployment) and the environmental quality (the emissions along the two margins). Section 2.1 briefs a production technology in the goods market. Section 2.2 introduces a matching technology in the labor market. Section 2.3 formulates a decision model for production, job-search, and abatement problems.

In our model, time is continuous. There is a continuum of utility-maximizing workers and profit-maximizing job positions. Both workers and job positions are risk-neutral and discount the future with an identical real interest rate r.[1] Workers are identical and live infinitely. Without loss of generality, we normalize the measure of workers to unity.

2.1 Production Technology

Labor and capital are the factors of production. They are used to produce two types of non-storable intermediate goods. These goods are sold in a competitive market and are transformed into the final good. The technology of production for the final good is

$$Y = \left(\alpha Y_d^{\rho} + (1-\alpha) Y_c^{\rho}\right)^{\frac{1}{\rho}}, \tag{1}$$

where Y_c and Y_d are the aggregate production of the two intermediate goods.[2] Y_c is produced in a nonpolluting sector that does not pollute the environment. In contrast, the production of Y_d emits harmful substances that pollute the environment. That is, Y_d is produced in a polluting sector. c and d are used to denote "clean" and "dirty" goods. The elasticity of substitution between the dirty good and the clean good is $1/(1-\rho)$, where $\rho < 1$. $\alpha \in (0, 1)$ is a parameter for the relative importance of the dirty good. The price of the final good is normalized to unity.

Since the markets for the two intermediate goods are competitive, the prices of the

[1] This assumption is common in the literature (Mortensen and Pissarides, 1994; Moen, 1997; Moscarini, 2005; Rogerson et al., 2005; Gonzalez and Shi, 2010; Fujita and Ramey, 2012; Michaillat, 2012). Applications of the search and matching model also assume agents to be risk-averse, such as the literature that investigates the optimal unemployment benefits with search frictions (Fredriksson and Holmlund, 2006; Guerrieri et al., 2010). Recent literature also investigates job search behaviors with the preference of ambiguity aversion (Chan and Yip, 2020). Our model can be easily extended to incorporate agents' ambiguity preferences; we do not do so because the modification of agents' preference towards ambiguity complicates our model without providing a richer economic intuition in our context.

[2] A similar constant elasticity of substitution (CES) aggregation function is also used in Hafstead and Williams (2018).

intermediate goods are

$$p_c = (1-\alpha)\left(\frac{Y}{Y_c}\right)^{1-\rho} \text{ and } p_d = \alpha\left(\frac{Y}{Y_d}\right)^{1-\rho}. \tag{2}$$

The production technology of intermediate goods is Leontief. When matched with a job position with necessary equipment, a worker produces $A > 0$ units of the respective good. The necessary equipment is sector-specific: it can only be used to produce either type of intermediate goods.

2.2 Search and Match in the Labor Market

Workers are assumed to be either employed or unemployed. Only unemployed workers search jobs. There is a free entry to create vacancies. A capital cost k is incurred to buy the sector-specific equipment to create a vacancy in a particular sector. At any point in time, a worker can work on only one job position and a position can only be filled by one worker.

Search is undirected. Both types of vacancies have the same probability of meeting workers. Workers and vacancies come together via a matching technology $M(u,v)$, where u is the unemployment rate and v is the vacancy rate (the total number of vacancies).[3] We make the standard assumptions in the literature: $M(u,v)$ is twice differentiable, increasing in both arguments, has constant returns to scale, and satisfies the standard Inada-type assumptions. Thus, the flow rate of match for a vacancy is $M(u,v)/v \equiv q(\theta)$, where $q(\cdot)$ is a differentiable decreasing function and $\theta \equiv v/u$ is the tightness of the labor market. Thus, the flow rate of match for an unemployed worker is $M(u,v)/u = \theta q(\theta)$.[4] $\theta q(\theta)$ is increasing in θ, $\lim_{\theta\to 0} q(\theta) = \infty$, $\lim_{\theta\to\infty} q(\theta) = 0$, $\lim_{\theta\to 0} \theta q(\theta) = 0$, and $\lim_{\theta\to\infty} \theta q(\theta) = \infty$.

We assume that all filled positions end with an exogenous flow rate $\lambda > 0$. The exogenous flow rate coheres with the job search literature (Hall, 2005; Shimer, 2005; Hagedorn and Manovskii, 2008; Hall and Milgrom, 2008) in that job-separation rate is treated acyclical. The assumption of exogeneity is also consistent with the empirical documentation in Yip (2021), which finds that the impact of a climate-change policy on job-separation rate quickly decays to zero.

Upon matching, the worker and the position bargain on the wage for producing good j. After bargaining, production starts, the position sells the product and pays the wage to the worker. [5] The worker holds the job until a separation shock arrives. When the separation

[3] Hafstead and Williams (2018) also assume that the two sectors hire from the same pool of workers.

[4] Endogenizing search intensity in this model is simple but would not result in richer economic intuition. No results in this paper would be altered by endogenizing search intensity.

[5] The model assumes that workers are hired only for production and not for other activities such as recruitment.

shock arrives, the filled position becomes vacant and the worker becomes unemployed. The flow return from unemployment is z, where z can be interpreted as the level of utility derived from leisure or the value of home production.

2.3 Bellman Equations

Our model will be solved through a series of Bellman equations. Let J_j^E be the discounted present value of employment in sector j and J^U be the discounted value of unemployment. Let J_j^F and J_j^V be the values of a filled job position and a vacancy in sector j, respectively.

The value function of employment can be written as follows:

$$rJ_j^E \quad = \quad w_j + \lambda(J^U - J_j^E). \tag{3}$$

Being employed is analogous to holding an asset. The employed worker in sector j receives a wage w_j just as receiving a dividend from an asset of being employed. While the employed becomes unemployed, they will receive the value of unemployment rather than employment. Hence, the value of the asset will drop from J_j^E to J^U with a probability λ, where $J^U - J_j^E$ captures the capital loss.

Let ϕ be the proportion of dirty-good vacancies among all vacancies. Since both types of vacancies meet workers at the same rate in a steady state, ϕ is the steady-state share of dirty-good jobs among all filled jobs. The value function of unemployment can be written as follows:

$$rJ^U \quad = \quad z + \theta q(\theta)\Big[\phi(J_d^E - J^U) + (1-\phi)(J_c^E - J^U)\Big]. \tag{4}$$

Holding the asset of unemployment, a worker receives a dividend of z. When the worker is employed, the asset of unemployment is transformed into the asset of employment. The associated capital gain will be $J_d^E - J^U$ with a probability ϕ and $J_c^E - J^U$ with a probability $1-\phi$.

A job position generates revenue $p_j A$ in sector j. A position may incur two types of costs: labor cost w_j and abatement cost. While the labor cost is incurred in both sectors, the abatement cost is not. Since a job position does not pollute in a nonpolluting sector, its abatement cost is zero. Jobs producing dirty goods choose the emission level to maximize the asset value of a filled job. They are required to pay the total cost $C(\bar{x} - x)$ of abating emission from an unabated level $\bar{x}$ to an abated level x. Taking wages as given, the asset

Readers who are interested in theoretical frameworks in which workers engage in recruitment are referred to Hafstead and Williams (2018). Also, the key results of this paper remain unchanged regardless of the presence of payroll tax.

value of a filled job producing good j is given by

$$\begin{aligned} rJ_c^F &= p_c A - w_c + \lambda(J_c^V - J_c^F) \text{ and} \\ rJ_d^F &= \max_{x\in[0,\bar{x}]} \Big[p_d A - w_d - C(\bar{x} - x) + \lambda(J_d^V - J_d^F) \Big]. \end{aligned} \tag{5}$$

We make the following assumptions on the cost function of abatement: $C : [0, \bar{x}_d] \longmapsto \mathbb{R}_+$. First, we assume the two sectors share an identical abatement cost function. The cost function is assumed twice differentiable. In the absence of abatement, the cost and the marginal cost are assumed zero. That is, $C(0) = 0$ and $C'(0) = 0$. Moreover, $C'(\cdot) > 0$ and $C''(\cdot) > 0$: the greater is the abatement level, the costlier is an additional unit of abatement. Furthermore, we assume $\lim_{x\to 0} C'(\bar{x} - x) = \infty$. Hence, it is infeasible to remove all pollutants in the polluting sector.

The optimal level of emission x^* satisfies the following first-order condition:

$$C'(\bar{x} - x^*) = 0. \tag{6}$$

Given the assumptions on the cost function of abatement, the optimal emission level x^* is given by $\bar{x}$. While abatement is costly, it does not provide any economic benefit to job positions. As a result, they will not abate emission (i.e., $x^* = \bar{x}$), and the abatement cost will be zero. We will introduce various climate-change policies in later sections. By then, the optimal emission level x^* may not equal the unabated level $\bar{x}$.

The asset value of a vacancy for producing good j is:

$$rJ_j^V = q(\theta) \left(J_j^F - J_j^V \right). \tag{7}$$

At the moment a worker meets a job, they bargain on the wage, leading to a rent sharing over the surplus of the match. We assume that the rent sharing rule is:

$$(1 - \beta)(J_j^E - J^U) = \beta(J_j^F - J_j^V), \tag{8}$$

where $\beta \in (0, 1)$. This rule is the implication of Nash bargaining between risk-neutral workers and jobs who have the same discount rate, where the worker has bargaining power β (Pissarides, 2000).

The free entry and exit of vacancies drive the expected gross profits of vacancies to the machinery cost k; thus

$$J_j^V = k. \tag{9}$$

Finally, the inflow and outflow of unemployment are equal in a steady state. Thus, the steady-state unemployment rate is given by

$$u = \frac{\lambda}{\lambda + \theta q(\theta)}. \tag{10}$$

2.4 Steady-State Equilibrium

Definition 1. *A steady-state equilibrium is defined as* $\{Y, p_j, w_j, x, u, \phi, \theta, J_j^E, J^U, J_j^F, J_j^V\}$ *such that for all* $j \in \{c, d\}$,

1. *(Production of Final Goods):* Y *satisfies equation (1);*
2. *(Goods Market Clearing): Prices of two intermediate goods* p_j *satisfy equation (2);*
3. *(Value Functions):* J_j^E, J^U, J_j^F, *and* J_j^V *satisfy equations (3), (4), (5), and (7);*
4. *(Optimal Emission Level): Emission level* x *satisfies equation (6);*
5. *(Rent Sharing): Wages for the two jobs* w_j *satisfy the sharing rule (8);*
6. *(Free Entry and Exit): The proportion of dirty-good jobs* ϕ *and market tightness* θ *satisfy equation (9);*
7. *(Steady-State Accounting): The unemployment rate* u *satisfies equation (10).*

We characterize the equilibrium objects as functions of ϕ and θ. In a steady-state equilibrium, the two aggregate intermediate goods are given by $Y_c = (1-u)(1-\phi)A$ and $Y_d = (1-u)\phi A$. Using equation (2), the prices are

$$\begin{aligned} p_c(\phi) &= (1-\alpha)\left\{\frac{[\alpha\phi^\rho + (1-\alpha)(1-\phi)^\rho]^{\frac{1}{\rho}}}{1-\phi}\right\}^{1-\rho} \quad \text{and} \\ p_d(\phi) &= \alpha\left\{\frac{[\alpha\phi^\rho + (1-\alpha)(1-\phi)^\rho]^{\frac{1}{\rho}}}{\phi}\right\}^{1-\rho}. \end{aligned} \tag{11}$$

p_c strictly increases with ϕ and p_d strictly decreases with ϕ. In a steady-state equilibrium, $\phi = Y_d/(Y_c+Y_d)$ is the quantity share of dirty goods in the market, which can be interpreted as the market share of the polluting sector. An increase in ϕ makes Y_c less relatively more abundant than Y_d, lowering p_c.

From equations (3), (5), (8), and (9), the wage equations are

$$\begin{aligned} w_c &= (1-\beta)rJ^U + \beta(p_c A - rk) \text{ and} \\ w_d &= (1-\beta)rJ^U + \beta\Big(p_d A - C(\bar{x} - x^*) - rk\Big), \end{aligned} \tag{12}$$

where x^* is the optimal emission level that satisfies the optimal emission scheme (6). A worker is compensated with fractions of his outside option value and the flow profits in the

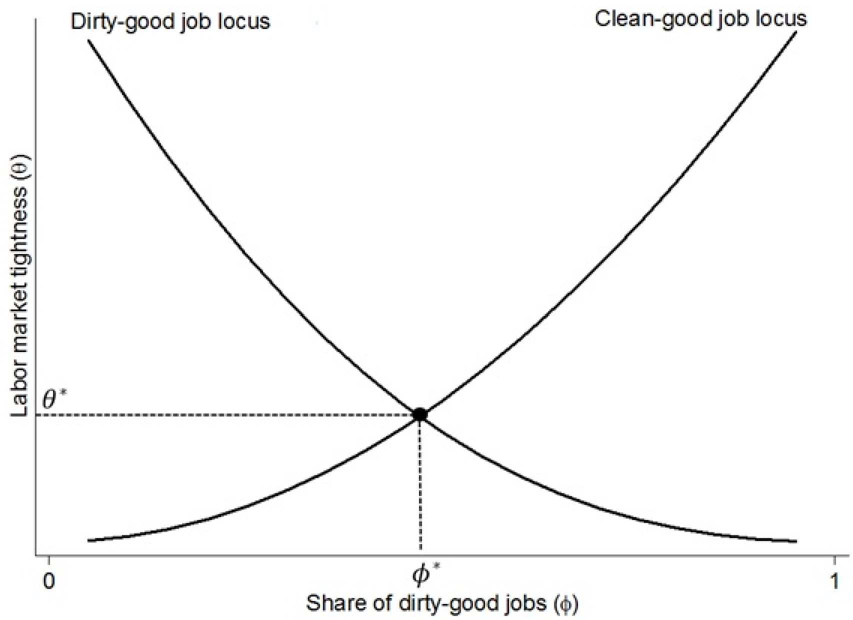


Figure 1: Equilibrium determination in the ϕ-θ plane

corresponding sector. Using equations (4), (7), (8), and (9), we have

$$rJ^U \quad = \quad z + \theta \frac{\beta}{1-\beta} rk. \tag{13}$$

rJ^U strictly increases with θ. Intuitively, higher market tightness shortens unemployment spell, increasing a worker's outside option value.

Equations (7), (8), (12), and (13) imply the following zero-profit conditions:

$$rk \quad = \quad \frac{q(\theta)(1-\beta)}{r+\lambda}\left(p_c(\phi)A - rk - z - \frac{\theta\beta rk}{1-\beta}\right) \text{ and} \tag{14}$$

$$rk \quad = \quad \frac{q(\theta)(1-\beta)}{r+\lambda}\left(p_d(\phi)A - C(\bar{x} - x^*) - rk - z - \frac{\theta\beta rk}{1-\beta}\right), \tag{15}$$

where x^* is the optimal emission level. Along each locus, vacancies in the corresponding sector make zero expected profits.

Proposition 1. *There exists a unique steady-state equilibrium, as defined in Definition 1.*

Proof. See Appendix 6.1. □

Figure 1 provides a graphical presentation of Proposition 1. It illustrates the determination of the equilibrium. In the $\phi - \theta$ plane, locus (14) slopes upward, and locus (15) slopes downward. An increase in the share of dirty-good jobs reduces the relative price of dirty goods, lowering the expected profits of its vacancies. The free exit assumption ensures that the supply of the dirty-good vacancies and thus market tightness decline to maintain the zero-profit condition (15). A similar intuition can be applied to explain the positive slope of locus (14). The two loci intersect only once in the domain $\phi \in (0, 1)$, and the intersection of the two loci pins down the steady-state equilibrium.

3 The Tradeoff Between Employment and Environment

This section analyses the employment-environment tradeoff. We find that a large class of climate-change policies cannot avoid the employment-environment tradeoff. The key features of these policies are twofold: they increase the flow cost in the polluting sector without subsidizing the nonpolluting one.

Our analysis begins with the measures of employment and environment. Since the population is normalized to unity, it is straightforward to capture employment with $1 - u$. We utilize an emission intensity to measure the environmental quality. In the steady-state equilibrium, there are $\phi(1 - u)$ jobs producing dirty goods, and each job emits x units of pollutants. We denote the *aggregate* emission level (i.e., the steady-state level of emission stock) by $\chi \equiv x\phi(1 - u)$.

Totally differentiating the aggregate emission level yields three margins of change in the aggregate emission level as follows:

$$d\chi = \underbrace{\phi(1-u)dx}_{\text{Intensive Margin}} + \underbrace{x(1-u)d\phi}_{\text{Extensive Margin}} + \underbrace{x\phi d(1-u)}_{\text{Scale Effect}}.$$

Changes in x and ϕ are adjustments in the intensive and extensive margins of emissions. A change in $1 - u$ represents the scale effect on emissions: holding emission per job and the composition of jobs constant, expanding employment leads to more emission stock in the steady-state equilibrium. Apparently, shutting down all production yields no emissions but is undesirable. We normalize the measure of the environmental quality using total emissions per unit of output. Using equation (1), the emission intensity φ is given by

$$\varphi \equiv \frac{\chi}{Y} = \frac{x\phi(1-u)}{\left(\alpha Y_d^\rho + (1-\alpha)Y_c^\rho\right)^{\frac{1}{\rho}}} = \frac{x\phi}{A\left(\alpha\phi^\rho + (1-\alpha)(1-\phi)^\rho\right)^{\frac{1}{\rho}}}. \tag{16}$$

This measure not only isolates the scale effect but also standardizes the emission level for each dollar of goods and services produced in an economy. It is straightforward to show that $\varphi(x, \phi)$ increases with x and ϕ. Holding the job composition constant, an increase in the intensive margin of emission will increase the emission intensity. Similarly, holding the emission per jobs constant, an increase in the market share of the polluting sector will deteriorate the environmental quality. The rest of this paper focuses on the tradeoff between the employment opportunity (i.e., $1-u$) and the environmental quality (i.e., $\varphi(x,\phi)$).

In what follows, we generalize Proposition 1. The proposition states the existence of the unique steady-state equilibrium in the absence of cost differential between the two sectors. Here, we formulate a general situation in which a policy imposes an additional flow cost $T \geq 0$ on job positions in the polluting sector. This additional cost could reflect a lump-sum tax, an emission tax, an abatement cost, etc. We define this class of policy in Definition 2.

Definition 2. *We define by $\mathcal{P}(x,T)$ a class of policy that shares the following features:*

1. *It incents each dirty-job position to emit $x \in [0,\bar{x}]$ units of pollutants,*
2. *It incurs a flow cost by $T \geq 0$ in each dirty-job position, and*
3. *It incurs no additional flow cost in each clean-job position.*

The characteristic of such a policy is that it only affects the flow cost of dirty-good production, not the clean one. Accordingly, we rewrite the zero-profit condition of a dirty-good job as

$$rk \;=\; \frac{q(\theta)(1-\beta)}{r+\lambda}\left(p_d(\phi)A - T - rk - z - \frac{\theta\beta rk}{1-\beta}\right). \tag{17}$$

The zero-profit condition of a clean-good job remains unchanged and is given by equation (14). So, the steady-state equilibrium can be pinned down by the intersection of the two zero-profit conditions (14) and (17) on the $\phi-\theta$ plane as shown in Figure 1. The proof of the existence and the uniqueness of the steady-state equilibrium can also be found in Appendix 6.1.

To elucidate the employment-environment tradeoff, we map the equilibrium conditions (14) and (17) from the ϕ-θ plane into the ϕ-u plane as shown in Figure 2. According to the steady-state unemployment equation (10), u strictly decreases with θ. Hence, u tends to zero when θ approaches positive infinity and to one when θ approaches zero. The increased flow cost in the polluting sector shifts up the locus (14), resulting in a higher unemployment rate and a lower market share of the polluting sector.

Intuitively, the increased flow cost lowers flow profits, decreasing the supply of dirty-good vacancies. The fewer vacancies make unemployed workers difficult to get a job, lengthening their spells of unemployment. This primary effect increases the unemployment through the shrinkage of the polluting sector.

The primary effect decreases the outside option value of workers. As such, workers are willing to receive a lower wage. The lower labor cost increases flow profits in the two sectors. Such an increase encourages the creation of vacancies in both sectors. Hence, the wage effect mitigates the shrinkage of employment in the polluting sectors and expands employment in the nonpolluting sector. While the wage effect operates in both sectors, the difference in flow profits between the two sectors remains unchanged. As such, the

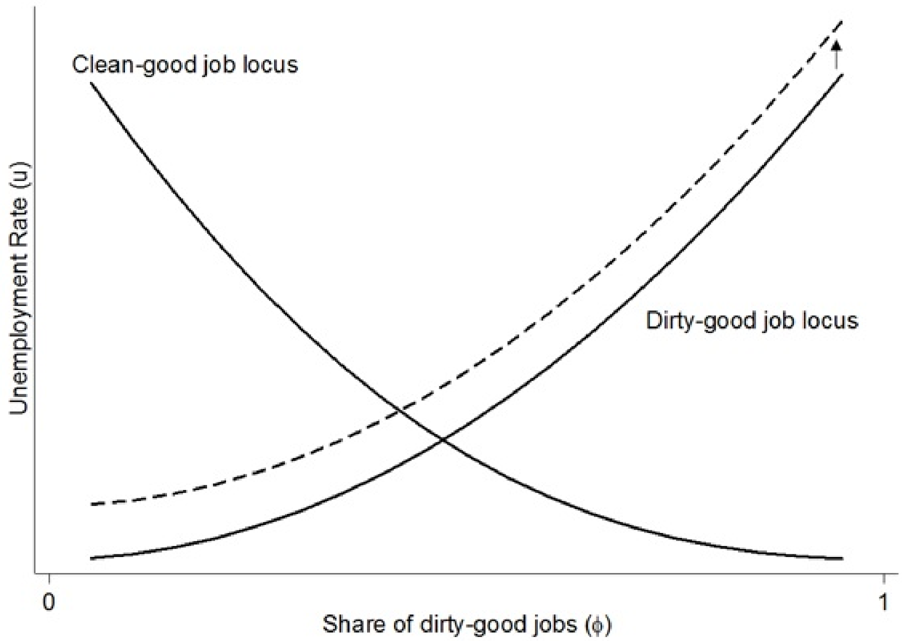


Figure 2: Equilibrium determination in the ϕ-u plane

wage effect mitigates the unemployment effect and leaves the market share of each sector unaffected.

Meanwhile, the increased flow cost will trigger a price effect. While the primary effect shrinks the polluting sector, the shrinkage will make clean goods relatively more abundant than dirty goods. As a result, p_c decreases and p_d increases. The increase in p_d enhances revenues and thus profits in dirty-good jobs, mitigating the unemployment effect in the polluting sector. In contrast, the decrease in p_c induces fewer vacancies created in the non-polluting sector. Therefore, the price effect will increase the market share of the polluting sector.

Here, we summarize the labor market responses to this class of policy. First, the market share of the polluting sector decreases. The increased flow cost makes the polluting sector less advantageous than its nonpolluting counterpart, reducing ϕ. Meanwhile, the price effect will ease the primary effect, whereas the wage effect plays no role in adjusting the market share. Consequently, this class of policies reduces ϕ.

Second, the unemployment increases and the wage decreases. Despite the wage and price effects, the primary effect of the increased flow cost shrinks the employment of the polluting sector. In contrast, the employment effect on the nonpolluting sector is ambiguous. While the wage effect increases the expected flow profits in the nonpolluting sector, its profits decrease through the price effect. It is, therefore, ambiguous to conclude whether such a policy will increase or decrease the expected flow profits and thus the employment in the nonpolluting sector. Such a policy increases the overall unemployment.

We can also see this from the steady-state employment in the polluting sector $\phi(1-u)$ and nonpolluting sector $(1-u)(1-\phi)$. Both the scale effect and the reduction in the market share of the polluting sector shrink the employment of the polluting sector $\phi(1-u)$. While the scale effect decreases the employment of the polluting sector, its market share increases. As a result, the employment effect is ambiguous in the nonpolluting sector.

What is the effect on the environmental quality? While the resulting market share of the polluting sector decreases, the emission intensity $\varphi(x, \phi)$ is improved from the extensive margin of emission ϕ. As long as the policy does not increase the intensive margin of emission x, it will bring the emission intensity $\varphi(x, \phi)$ down and enhance the environmental quality.

It is straightforward to see that the larger the increased cost T, the larger the unemployment rate and the smaller the market share of the polluting sector. This can be seen in Figure 2 that the larger the cost T, the more the locus (17) shifts upward. Consequently, the unemployment rate will increase more and the share of dirty-good jobs will decrease more.

Corollary 1. *If a policy increases a flow cost in dirty-good jobs, the steady-state unemployment u^* increases with T and ϕ^* decreases with T. That is, $u^{*\prime}(T) > 0$ and $\phi^{*\prime}(T) < 0$ for all $T \geq 0$.*

If a larger T induces a lower level of emission along its intensive margin, the policy associated with the larger T will decrease the emission intensity $\varphi(x, \phi)$ and improve the environmental quality. By adjusting T, this class of policy will either enhance the environmental quality at the expense of the employment opportunity or enhance the employment opportunity at the expense of the environmental quality. In other words, the employment-environment tradeoff is inevitable within this class of policy. We summarize our findings in Proposition 2.

Proposition 2. *$\forall\,(x_1, x_2) \in [0, \bar{x}] \times [0, \bar{x}]$ and $(T_1, T_2) \in \mathbb{R}^2$, if $x_1 \leq x_2$ and $T_1 > T_2$, then $\mathcal{P}(x_1, T_1)$ and $\mathcal{P}(x_2, T_2)$ cannot simultaneously achieve a better environmental quality and a lower unemployment rate than each other, where $\mathcal{P}(x, T)$ is a policy defined by Definition (2).*

This proposition enhances our understanding of the employment-environment tradeoff. It is clear that the additional flow cost of a policy lowers the profits of dirty-good firms, hurting the competitiveness of dirty-good firms relative to their clean-goods counterparts. If the policy does not increase the intensive margin of emission, such a policy must lower the emission intensity. Meanwhile, the increased flow cost hurts the competitiveness of dirty-good firms, discouraging job creation and thus creating unemployment. Hence, the proposition provides a key to break such a tradeoff: it is essential to cut cost in clean-goods job positions so as to avoid the employment-environment tradeoff.

It is noteworthy that $\mathcal{P}(\bar{x}, 0)$ is a situation in which there is no additional flow cost imposed by any policy and at the same time, jobs do not abate emission. In other words,

$\mathcal{P}(\bar{x}, 0)$ is a policy instrument that is equivalent to a "no climate-change policy" situation. An important special case of Proposition 2, therefore, emerges: if we introduce a climate-change policy, which increases the flow cost in the polluting sector, to an economy with no climate-change policy, the employment-environment tradeoff is inevitable.

This proposition lays the theoretical foundation of the conflicts between two lobbying groups in the literature on the political economy of climate-change policy (Aidt, 1998; Fredriksson and Svensson, 2003; Oates and Portney, 2003; List and Sturm, 2006). Environmental organizations lobby against the situation $\mathcal{P}(\bar{x}, 0)$ because there always exists a broad class of policies $\mathcal{P}(x, T)$ that could improve the environmental quality. Meanwhile, the public, including business owners and labor unions, may lobby against climate-change legislation because a broad class of policy sacrifices job opportunities. Therefore, Proposition 2 identifies political parties concerning climate-change legislation, explains why climate-change policy arouses their attention, and reveals how the political dilemma of climate-change policy emerges.

Proposition 2 is indeed rich in implication. The wide class of policy includes a lump-sum tax on firms in the polluting sector, simple emission tax with the emission tax revenue abstracted from the labor market, intensity standards, etc. As explained, $\mathcal{P}(\bar{x}, 0)$ belongs to this class of policy defined in 2. Therefore, Proposition 2 could describe the situation in which a climate-change policy is introduced to an economy without any preexisting climate change policy. Meanwhile, Proposition 2 allows us to analyze another type policy scenario—a climate-change policy is introduced to an economy in the presence of preexisting climate change policy.

For example, Proposition 2 sheds light on the tradeoff among the same type of policy with various degrees of stringency. Section 4.1 will apply the proposition to show that adjusting an emission tax rate cannot avoid the tradeoff. Given an emission tax rate, there does not exist any emission tax rate that yields a better environmental quality without hurting employment opportunity. With the application of Proposition 2, Section 4.2 will reach a similar conclusion about intensity standards. Another example is the employment-environment tradeoff between two different types of policies. Section 4.3 will illustrate the application of Proposition 2 to understand the tradeoff between an emission tax and an intensity standard.

4 Comparisons Between Climate-Change Policies

This section continues the analysis of the employment-environment tradeoff within the large class of policy defined in Definition 2. In particular, we will pay special attention to an emission tax policy and an intensity standard.

Section 4.1 analyzes the tradeoff in the situation in which an emission tax was introduced to an economy in the absence of climate-change policy. It shows that simply adjusting an emission tax rate cannot break the tradeoff because an emission tax policy belongs to the class of policy defined in Definition 2. For the same reason, Section 4.2 shows that replacing one level of an intensity standard by another level cannot break the tradeoff.

Section 4.3 analyzes the tradeoff between an emission tax policy and an intensity standard. We show that intensity standards are superior to emission taxes in the labor market: while policymakers can always find an intensity standard policy to replace a preexisting emission tax to simultaneously enhance the employment opportunity and environmental quality, there exists no such an emission tax rate that a policy shift from a preexisting intensity standard to an emission tax policy can improve the environmental quality without hurting the employment opportunity.

4.1 Emission Taxes

This section shows that neither the introduction of emission taxes to the economy in the absence of climate-change policy nor the substitution of one emission tax rate for another rate can break the employment-environment tradeoff. We establish the claim through two major steps: first, we demonstrate that an emission tax policy belongs to the class of policy defined by Definition 2, and second, we demonstrate that adjusting an emission tax rate satisfies conditions that trigger Proposition 2.

Our analysis begins with the details of an emission tax policy. We denote by $\mathcal{ET}(\tau)$ an emission tax policy. It charges each job position $\tau > 0$ per unit of pollutants. We assume that emission tax revenues are abstracted from the labor market; for example, the tax revenues could be distributed to households in a lump-sum manner.

Under $\mathcal{ET}(\tau)$, a dirty-good job, taking wages as given, chooses the optimal emission level to maximize the asset value of a job position. Therefore, the asset value of each job position (5) can be rewritten as follows:

$$\begin{aligned} rJ_c^F &= p_c A - w_c + \lambda(J_c^V - J_c^F) \text{ and} \\ rJ_d^F &= \max_{x\in[0,\bar{x}]} p_d A - w_d - C(\bar{x} - x) - \tau x + \lambda(J_d^V - J_d^F). \end{aligned} \tag{18}$$

We denote by $x_{\mathcal{ET}}(\tau)$ the optimal emission level for a dirty-good job under $\mathcal{ET}(\tau)$. The optimal emission level $x_{\mathcal{ET}}(\tau)$ satisfies the following first-order condition:

$$\underbrace{\tau}_{\text{Marginal Abatement Benefit}} = \underbrace{C'(\bar{x} - x_{\mathcal{ET}}(\tau))}_{\text{Marginal Abatement Cost}}. \tag{19}$$

Abatement continues until its marginal benefit equals its marginal cost. To abate an additional unit of emission saves the emission tax payment of the additional unit, which is τ. Hence, the marginal benefit of abatement equals the emission tax rate τ. Apparently, an additional unit of abatement incurs the marginal cost of abatement. Therefore, each job

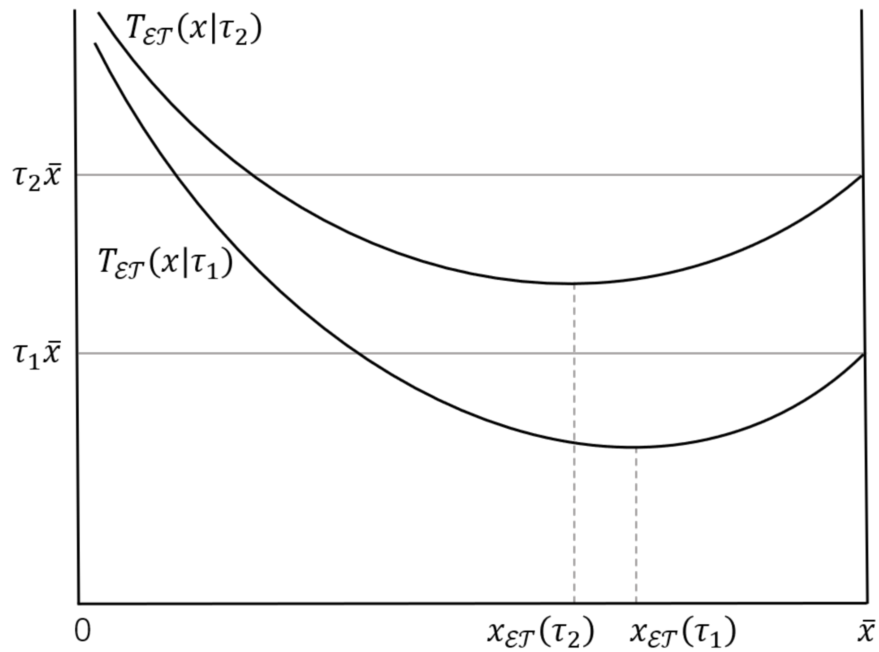


Figure 3: This graph demonstrates the flow cost of an emission tax policy as a function of an emission level.

position selects the emission level $x_{\mathcal{ET}}(\tau)$ that satisfies first-order condition (19).

A unique $x_{\mathcal{ET}}(\tau)$ exists. Under the assumptions of $\lim_{x\to\bar{x}} C'(\bar{x}-x) = 0$ and $\lim_{x\to 0} C'(\bar{x}-x) = \infty$, the intermediate value theorem ensures the existence of $x \in (0, \bar{x})$ that solves equation (19). Since $C''(\bar{x}-x) > 0$, $x_{\mathcal{ET}}(\tau)$ is unique.

A steady-state equilibrium exists under $\mathcal{ET}(\tau)$. We modify the definition of a steady-state equilibrium. All but two conditions stated in Definition 1 are satisfied in the steady-state equilibrium under $\mathcal{ET}(\tau)$. Here are two exemptions: first, the asset values of job positions J^F are given by equation (18) instead of equation (5), and second, the optimal emission level satisfies equation (19) instead of equation (6). The proof of its existence and uniqueness can be found in Appendix 6.1.

Indeed, $\mathcal{ET}(\tau)$ belongs to the class of policy $\mathcal{P}(x, T)$ defined by Definition (2). $\mathcal{ET}(\tau)$ incurs a flow cost in each dirty-good job position. Each dirty-good job position is required to pay an emission tax payment τx and an abatement cost $C(\bar{x}-x)$. Under $\mathcal{ET}(\tau)$, the flow cost $T_{\mathcal{ET}}(x|\tau)$ is a function of emission. That is, $T_{\mathcal{ET}}(x|\tau) = \tau x + C(\bar{x}-x)$.

By the envelop theorem, it is equivalent for a job position to choose between the optimal emission level to maximize the asset value of dirty-good job position (i.e., equation (18)) and the optimal emission level to minimize the flow cost incurred by the policy $\mathcal{ET}(\tau)$. To further our understanding, we demonstrate the flow cost $T_{\mathcal{ET}}(x|\tau)$ incurred by $\mathcal{ET}(\tau)$ as a function of an emission level in Figure 3.

Let's take $\mathcal{ET}(\tau_1)$ as an example. When a job position does not abate emission, its emission level is $\bar{x}$ and the job position is required to pay the emission tax payment $\tau_1 \bar{x}$. Without abatement, it does not incur any abatement cost. That is, $T_{\mathcal{ET}}(\bar{x}|\tau_1) = \tau_1 \bar{x}$. For each unit of abatement, it saves the job position the tax payment of τ_1, the marginal benefit of abatement, and incurs the marginal cost of abatement. Initially, the position finds it beneficial to abate because the marginal cost of abatement is lower than τ_1. As a result, the flow cost continues to decrease when an emission level x departs further from an unabated level $\bar{x}$. While the marginal benefit of abatement is fixed at τ_1, the marginal cost of abatement increases with the abatement level. The position emits at the level of $x_{\mathcal{ET}}(\tau_1)$ at which τ_1 equals the marginal cost of abatement. In other words, $x_{\mathcal{ET}}(\tau_1)$ is chosen because the flow cost reaches its minimum at $x_{\mathcal{ET}}(\tau_1)$. At the optimum, the flow cost $T_{\mathcal{ET}}(\tau_1) = \tau_1 x_{\mathcal{ET}}(\tau_1) + C(\bar{x} - x_{\mathcal{ET}}(\tau_1))$ under $\mathcal{ET}(\tau_1)$.

Hence, $\mathcal{ET}(\tau)$ belongs to $\mathcal{P}(x_{\mathcal{ET}}(\tau), T_{\mathcal{ET}}(\tau))$, where $\mathcal{P}(x, T)$ is defined in Definition 2. First of all, $\mathcal{ET}(\tau)$ incents each dirty-job position to emit $x_{\mathcal{ET}}(\tau) \in [0, \bar{x}]$ units of pollutants. Second, the policy incurs a flow cost by $T_{\mathcal{ET}}(\tau) \geq 0$ in each dirty-job position. Third, it incurs no additional flow cost in each clean-job position. Hence, $\mathcal{ET}(\tau) \subset \mathcal{P}(x_{\mathcal{ET}}(\tau), T_{\mathcal{ET}}(\tau))$. The direct application of Proposition 2 implies the following theorem:

Theorem 1. *For all $\tau > 0$, the introduction of $\mathcal{ET}(\tau)$ to an economy in the absence of preexisting climate-change policy cannot break the employment-environment tradeoff.*

Proof. We showed that $\mathcal{ET}(\tau) \subset \mathcal{P}(x_{\mathcal{ET}}(\tau), T_{\mathcal{ET}}(\tau))$. As noted above, $\mathcal{P}(\bar{x}, 0)$ is a situation in which an economy does not have any climate-change policy. Since $x_{\mathcal{ET}}(\tau) < \bar{x}$, $T_{\mathcal{ET}}(\tau) > 0$, and τ is arbitrary, Proposition 2 implies that for all $\tau > 0$, $\mathcal{P}(x_{\mathcal{ET}}(\tau), T_{\mathcal{ET}}(\tau))$ and $\mathcal{P}(\bar{x}, 0)$ cannot simultaneously achieve a better environmental quality and a lower unemployment rate than each other. □

Corollary 2. *The introduction of $\mathcal{ET}(\tau)$ enhances the environmental quality at the expense of employment.*

Proof. According to Corollary 1, $u^{*\prime}(T) > 0$ and $\phi^{*\prime}(T) < 0$. Hence, $T_{\mathcal{ET}}(\tau) > 0$ and $u^{*\prime}(T) > 0$ implies that the introduction of $\mathcal{ET}(\tau)$ decreases employment; meanwhile, $x_{\mathcal{ET}}(\tau) < \bar{x}$ and $\phi^{*\prime}(T) < 0$ implies that $\varphi(x_{\mathcal{ET}}(\tau), \phi^*(T_{\mathcal{ET}}(\tau))) < \varphi(\bar{x}, \phi^*(0))$. □

Next, we explore another type of policy scenario. Suppose an economy has an emission tax policy $\mathcal{ET}(\tau)$. Can we break the tradeoff by adjusting the emission tax rate τ? This question is informative because for decades, a variant of emission tax, like $\mathcal{ET}(\tau)$, was introduced to developed countries such as Finland in 1990, Norway in 1991, Sweden in 1991, Denmark in 1992, etc. When employment is a concern for climate-change policies, the public, economists, policymakers, and even scientists may wonder whether we can enhance the employment opportunity and environmental quality simply by adjusting the emission tax rate.

To answer the question, we first explore the effects of a higher tax rate on the emission and flow cost. Figure 3 demonstrates the example of two tax rates $\tau_1 < \tau_2$. Recall that a dirty-good job position abates emissions to save an emission tax payment. Therefore, a higher emission tax rate increases the marginal benefit of abatement and thus incents abatement. To see this from our model, one can totally differentiate equation (19) with respect to an emission tax rate τ to yield

$$x'_{\mathcal{ET}}(\tau) = \frac{-1}{C''(\bar{x} - x_{\mathcal{ET}}(\tau))} < 0.$$

Meanwhile, a higher emission tax incurs a higher flow cost $T_{\mathcal{ET}}(\tau) = \tau x_{\mathcal{ET}}(\tau) + C(\bar{x} - x_{\mathcal{ET}}(\tau))$. By the envelope theorem, totally differentiating the flow cost with respect to τ yields

$$T'_{\mathcal{ET}}(\tau) = x_{\mathcal{ET}}(\tau) > 0.$$

The above two derivatives jointly suggest that a higher emission tax rate incents abatement, cut emissions, and incurs an additional flow cost. The two derivatives are important to verify the employment-environment tradeoff within the class of emission tax policy $\mathcal{ET}(\tau)$. Since $\mathcal{ET}(\tau) \subset \mathcal{P}(x_{\mathcal{ET}}(\tau), T_{\mathcal{ET}}(\tau))$ for all $\tau > 0$, $x'_{\mathcal{ET}}(\tau) < 0$ and $T'_{\mathcal{ET}}(\tau) > 0$ satisfy the conditions that trigger Proposition 2 to yield the following theorem:

Theorem 2. *For any $\tau_1 > 0$ and $\tau_2 > 0$, the substitution of $\mathcal{ET}(\tau_1)$ for $\mathcal{ET}(\tau_2)$ cannot break the employment-environment tradeoff.*

A higher emission tax rate improves the environmental quality. While a higher emission tax rate incents abatement, it lowers the intensive margin of emission (i.e., $x'_{\mathcal{ET}}(\tau) < 0$). According to Corollary 1, $\phi^{*\prime}(T) < 0$. $\phi^{*\prime}(T) < 0$ and $T'_{\mathcal{ET}}(\tau) > 0$ jointly imply that $\phi^{*\prime}(\tau) < 0$. The higher tax rate discourages the creation of dirty-good jobs, shrinking the market share of the polluting sector. Thus, the higher emission tax rate lowers the extensive margin of emission (i.e., $\phi^{*\prime}(\tau) < 0$)). As a result, the emission intensity $\varphi(x, \phi)$ is a function of an emission tax rate under $\mathcal{ET}(\tau)$. In particular, $\varphi'(\tau) < 0$.

A higher emission tax rate increases unemployment. According to Corollary 1, $u^{*\prime}(T) > 0$. $u^{*\prime}(T) > 0$ and $T'_{\mathcal{ET}}(\tau) > 0$ imply that $u^{*\prime}(\tau) > 0$. A higher tax rate decreases employment through the increased flow cost of abatement and tax payment in the polluting sector. Corollary 3 summarizes the findings:

Corollary 3. *The substitution of a higher emission tax rate for a lower one enhances the environmental quality at the expense of employment.*

This section shows that emission taxes belong to the large class of climate-change policy defined in Definition 2. This class of policy cannot avoid the curse of climate-change policies: they can either enhance the environmental quality or the employment opportunity, not both. We show that not only does the introduction of a new emission tax policy fail to achieve the two goals, but also the substitution of any emission tax for a preexisting one cannot break the tradeoff.

Section 4.3 will analyse the employment-environment tradeoff between emission taxes and intensity standards. Before that, we continue the analysis of such a tradeoff within the class of intensity standards in the next section.

4.2 Intensity Standards

This section shows that an intensity standard policy belongs to the class of climate-change policy defined in Definition 2. Hence, the introduction of an intensity standard to an economy in the absence of preexisting climate-change policy fails to simultaneously achieve the two goals—a better employment opportunity and environmental quality. In the end of this section, we show that substituting one intensity standard for another one cannot break the employment-environment tradeoff.

Our analysis begins with the details of an intensity standard policy. We denote by $\mathcal{IS}(\hat{x})$ an intensity standard, where $\hat{x} \in [0, \bar{x})$. It restricts a job position from emitting over the cap level (i.e., the standard), which is $\hat{x}$ units of pollutants per A units of production. Hence, $\mathcal{IS}(\hat{x})$ shrinks the set of a choice variable—the emission level, from $[0, \bar{x}]$ to $[0, \hat{x})$. If the restricted level $\hat{x}$ equals the unabated level $\bar{x}$, the intensity standard policy does not limit the level of emission and the policy is unbinding. To have meaningful analyses, we restrict our analysis to the case of $\hat{x} \in [0, \bar{x})$.

$\mathcal{IS}(\hat{x})$ may alter an abatement decision in the polluting sector. While an intensity standard has no direct impact on clean-good job positions, it limits the choice set of an emission level and requires each dirty-good job position to pay an abatement cost. Under $\mathcal{IS}(\hat{x})$, a dirty-good job chooses the optimal emission level to maximize the discounted present value of a job. We can rewrite the value function (5) as

$$\begin{aligned} rJ_c^F &= p_c A - w_c + \lambda(J_c^V - J_c^F) \text{ and} \\ rJ_d^F &= \max_{x \in [0,\hat{x}]} p_d A - w_d - C(\bar{x} - x) + \lambda(J_d^V - J_d^F). \end{aligned} \tag{20}$$

We denote by $x_{\mathcal{IS}}(\hat{x})$ the optimal emission level for a dirty-good job under $\mathcal{IS}(\hat{x})$ and denote by $T_{\mathcal{IS}}(x|\hat{x})$ the flow cost incurred by $\mathcal{IS}(\hat{x})$. Similar to emission taxes, intensity standards impose an abatement cost $C(\bar{x} - x)$ on each dirty-good job position so as to abate emissions. Unlike emission taxes, intensity standards do not require job positions to pay any emission tax payment. Hence, $T_{\mathcal{IS}}(x|\hat{x}) = C(\bar{x} - x)$. According to equation (20), choosing an emission level to maximize the value function (20) is equivalent to picking an emission level to minimize a flow cost $T_{\mathcal{IS}}(x|\hat{x})$.

To better understand the decision on abatement, we demonstrate the flow cost $T_{\mathcal{IS}}(x|\hat{x})$

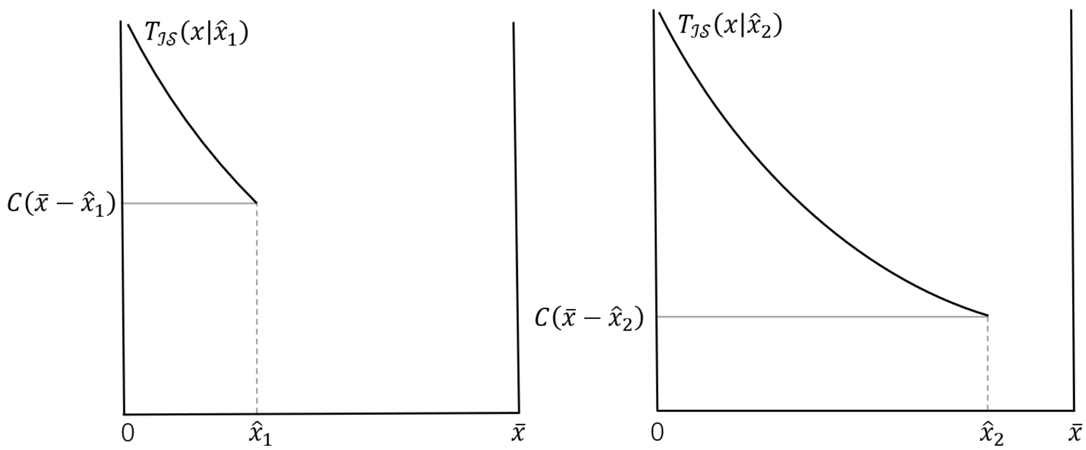


Figure 4: This graph demonstrates the flow cost of intensity standard policy as a function of an emission level.

incurred by $\mathcal{IS}(\hat{x})$ as a function of an emission level in Figure 4. $T_{\mathcal{IS}}(x|\hat{x})$ slopes downwards because the more a job position abates, the lower the emission level and the higher the abatement cost. Since the flow cost decreases with an emission level, we have a corner solution for the optimal emission level. To minimize the abatement cost, each position would like to abate as little as it can. Under $\mathcal{IS}(\hat{x})$, it is optimal for a dirty-good job position to emit at the cap level $\hat{x}$. That is, $x_{\mathcal{IS}}(\hat{x}) = \hat{x}$. To emit at the cap level, each dirty-good job position incurs a flow cost equal to an abatement cost $T_{\mathcal{IS}}(\hat{x}) = C(\bar{x} - \hat{x})$.

Hence, $\mathcal{IS}(\hat{x})$ belongs to the class of policy defined in Definition 2. While $\mathcal{IS}(\hat{x})$ incents each dirty-job position to emit $\hat{x} \in [0, \bar{x}]$ units of pollutants, it incurs a flow cost by $T_{\mathcal{IS}}(\hat{x}) \geq 0$ in each dirty-job position. Meanwhile, the policy incurs no additional flow cost in each clean-job position. Therefore, we can conclude that $\mathcal{IS}(\hat{x}) \subset \mathcal{P}(\hat{x}, T_{\mathcal{IS}}(\hat{x}))$ and the direct application of Proposition 2 leads to the following theorem:

Theorem 3. *For all $\hat{x} \in [0, \bar{x})$, the introduction of $\mathcal{IS}(\hat{x})$ to an economy in the absence of preexisting climate-change policy cannot break the employment-environment tradeoff.*

Proof. As mentioned, $\mathcal{P}(\bar{x}, 0)$ is a situation in which an economy does not have any climate-change policy. Since $x_{\mathcal{IS}}(\hat{x}) < \bar{x}$, $T_{\mathcal{IS}}(\hat{x}) > 0$, and $\hat{x}$ is arbitrary, Proposition 2 implies that for all $\hat{x} \in [0, \bar{x})$, $\mathcal{P}(x_{\mathcal{IS}}(\hat{x}), T_{\mathcal{IS}}(\hat{x}))$ and $\mathcal{P}(\bar{x}, 0)$ cannot simultaneously achieve a better environmental quality and a lower unemployment rate than each other. □

Next, we explore the employment-environment tradeoff in another policy scenario. Suppose an economy has a preexisting intensity standard $\mathcal{IS}(\hat{x})$. Can we achieve a better environmental quality and employment opportunity by adjusting the $\hat{x}$? The rest of this subsection will answer this question.

Intensity standards decrease its stringency with $\hat{x}$. As shown in Figure 4, if the standard increases from $\hat{x}_1$ to $\hat{x}_2$, the choice set of an emission level will expand from $[0, \hat{x}_1]$ to

$[0, \hat{x}_2]$. Since dirty-good job positions are permitted to emit more, they will abate less and hence, increase emissions from $\hat{x}_1$ to $\hat{x}_2$ to pay a lower flow cost. Mathematically, we have

$$x'_{\mathcal{IS}}(\hat{x}) = 1.$$

Totally differentiating the flow cost with respect to $\hat{x}$ yields

$$T'_{\mathcal{IS}}(\hat{x}) = -C'(\bar{x} - \hat{x}) < 0.$$

While $\mathcal{IS}(\hat{x}) \subset \mathcal{P}(\hat{x}, T_{\mathcal{IS}}(\hat{x}))$, $x'_{\mathcal{IS}}(\hat{x}) > 0$ and $T'_{\mathcal{IS}}(\hat{x}) < 0$ trigger Proposition 2 to yield Theorem 4.

Theorem 4. *For any $\hat{x}_1 \in [0, \bar{x})$ and $\hat{x}_2 \in [0, \bar{x})$, the substitution of $\mathcal{IS}(\hat{x}_1)$ for $\mathcal{IS}(\hat{x}_2)$ cannot break the employment-environment tradeoff.*

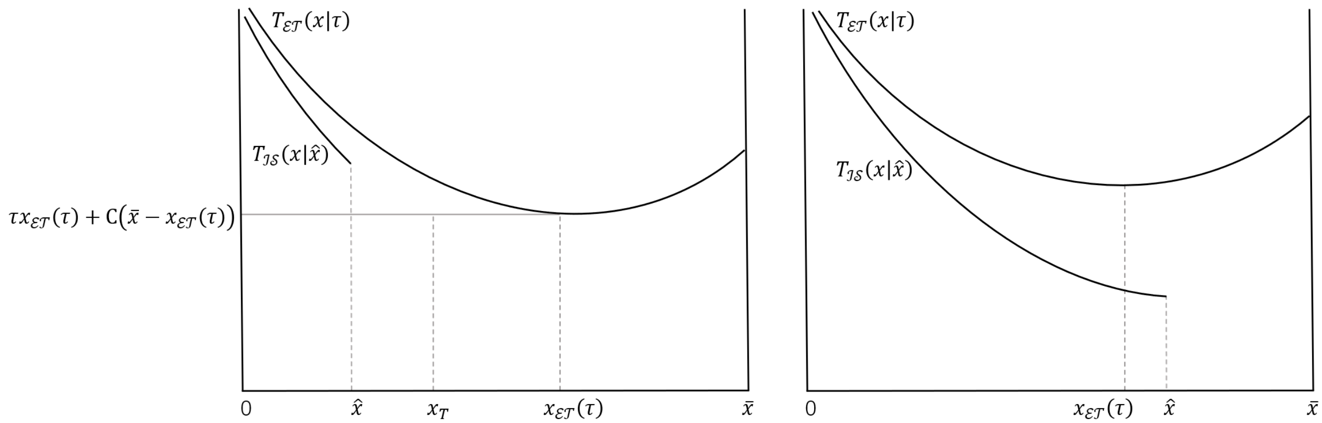
A lower $\hat{x}$ of intensity standards improves the environmental quality. The lower $\hat{x}$ forces each dirty-good job position to abate emission, increasing the degree of stringency. As such, a more stringent intensity standard reduces the intensive margin of emission. Meanwhile, a more stringent intensity standard increases the flow cost through abatement. That is, $T'_{\mathcal{IS}}(\hat{x}) < 0$. According to Corollary 1, $\phi^{*\prime}(T) < 0$. $\phi^{*\prime}(T) < 0$ and $T'_{\mathcal{IS}}(\hat{x}) < 0$ imply that $\phi^{*\prime}(\hat{x}) > 0$. The higher additional flow cost of a more stringent intensity standard discourages the creation of dirty-good jobs, shrinking the market share of the polluting sector. Hence, a more stringent intensity standard lowers the extensive margin of emission. Altogether, the lower $\hat{x}$ decreases both margins of emission and the emission intensity is a function of $\hat{x}$ under $\mathcal{IS}(\hat{x})$. In particular, $\varphi'(\hat{x}) > 0$. The lower $\hat{x}$ decreases the emission intensity.

The lower $\hat{x}$ of intensity standards decreases employment. A more stringent intensity standard incurs a higher abatement cost. According to Corollary 1, $u^{*\prime}(T) > 0$. $u^{*\prime}(T) > 0$ and $T'_{\mathcal{IS}}(\hat{x}) < 0$ imply that $u^{*\prime}(\hat{x}) < 0$. As such, the stringent intensity standards decrease employment through the higher abatement cost. The following corollary summarizes the findings.

Corollary 4. *A more stringent intensity standard increases the environmental quality at the expense of employment.*

Thus far, we have explained why the introduction of a new climate-change policy, such as an emission tax and an intensity standard, cannot break the employment-environment tradeoff. We have also demonstrated that we cannot achieve the two goals simply by adjusting the tax rate of a preexisting emission tax policy or adjusting the standard of a preexisting intensity standard policy.

Figure 5: The Substitution of Intensity Standards for Emission Taxes



Notes: The left panel shows that given an emission tax rate $\tau > 0$, there exists a unique $x_T < x_{\mathcal{ET}}(\tau)$ such that $\mathcal{ET}(\tau)$ incurs a lower flow cost than $\mathcal{IS}(\hat{x})$ for all $\hat{x} < x_T$. The right panel shows that given an emission tax rate $\tau > 0$, $\mathcal{ET}(\tau)$ incurs a higher flow cost than $\mathcal{IS}(\hat{x})$ for all $\hat{x} \geq x_{\mathcal{ET}}(\tau)$.

4.3 Comparisons Between Emission Taxes and Intensity Standards

This section analyzes two policy scenarios. Suppose there was an emission tax policy in an economy. One day, policymakers want to improve the natural and business environments. What are our options? Section 4.1 shows that adjusting the emission tax rate cannot avoid the employment-environment tradeoff. Can we substitute an intensity standard for the preexisting emission tax policy to simultaneously enhance the environmental quality and employment opportunity? Does such an intensity standard exist?

Similarly, if an economy begins with an intensity standard policy, can policymakers substitute an emission tax policy for the preexisting intensity standard to achieve the two goals? This question is interesting and highly policy-relevant because Section 4.2 shows that simply adjusting the standard cannot break the tradeoff. Policymakers may want to shift from intensity standards to emission taxes to enhance the natural and business environments. However, does such an emission tax exist? This section answers all these questions.

We begin our analysis with the first policy scenario. That is, each job position is charged $\tau > 0$ per unit of pollutants (i.e., $\mathcal{ET}(\tau)$). According to equation (19), each dirty-good job position will find it optimal to emit $x_{\mathcal{ET}}(\tau)$ unit of pollutants. The increased flow cost is equal to $T_{\mathcal{ET}}(\tau) = \tau x_{\mathcal{ET}}(\tau) + C(\bar{x} - x_{\mathcal{ET}}(\tau))$. The optimal emission level $x_{\mathcal{ET}}(\tau)$ and the increased flow cost $T_{\mathcal{ET}}(\tau)$ are two pieces of information required in our analysis.

We claim that there exist intensity standards that yield a better environmental quality and employment opportunity than the preexisting $\mathcal{ET}(\tau)$. We establish the claim with three critical emission levels.

The first critical level is the emission level x_T at which the intensity standard will incur the same amount of increased flow cost as the preexisting emission tax policy does. That is, $T_{\mathcal{IS}}(x_T) = T_{\mathcal{ET}}(x_{\mathcal{ET}}(\tau))$. We also present x_T in the left panel of Figure 5.

This critical emission level x_T exists and is unique. Given $\hat{x} = x_T$, each dirty-good job position will find it optimal to emit at the level of x_T. That is, $x_{\mathcal{IS}}(\hat{x}) = \hat{x}$. When the $\hat{x}$ approaches zero, the increased flow cost is higher under an intensity standard than the preexisting emission tax policy because the abatement cost of the intensity standard tends to infinity (i.e., $\lim_{\hat{x}\to 0} T_{\mathcal{IS}}(\hat{x}) = \lim_{\hat{x}\to 0} C(\bar{x} - \hat{x}) = \infty$). At $\hat{x} = x_{\mathcal{ET}}(\tau)$, the intensity standard incurs a lower flow cost than the preexisting emission tax policy because the intensity standard pays an identical abatement cost but no emission tax payment as the preexisting emission tax policy does. By the continuity of the flow cost function, the intermediate value theorem implies the existence of the level of x_T between zero and $x_{\mathcal{ET}}(\tau)$ such that $T_{\mathcal{IS}}(x_T) = T_{\mathcal{ET}}(x_{\mathcal{ET}}(\tau))$. Since the flow cost is strictly monotone, x_T is unique. Hence, we can conclude that a unique $x_T < x_{\mathcal{ET}}(\tau)$ exists.

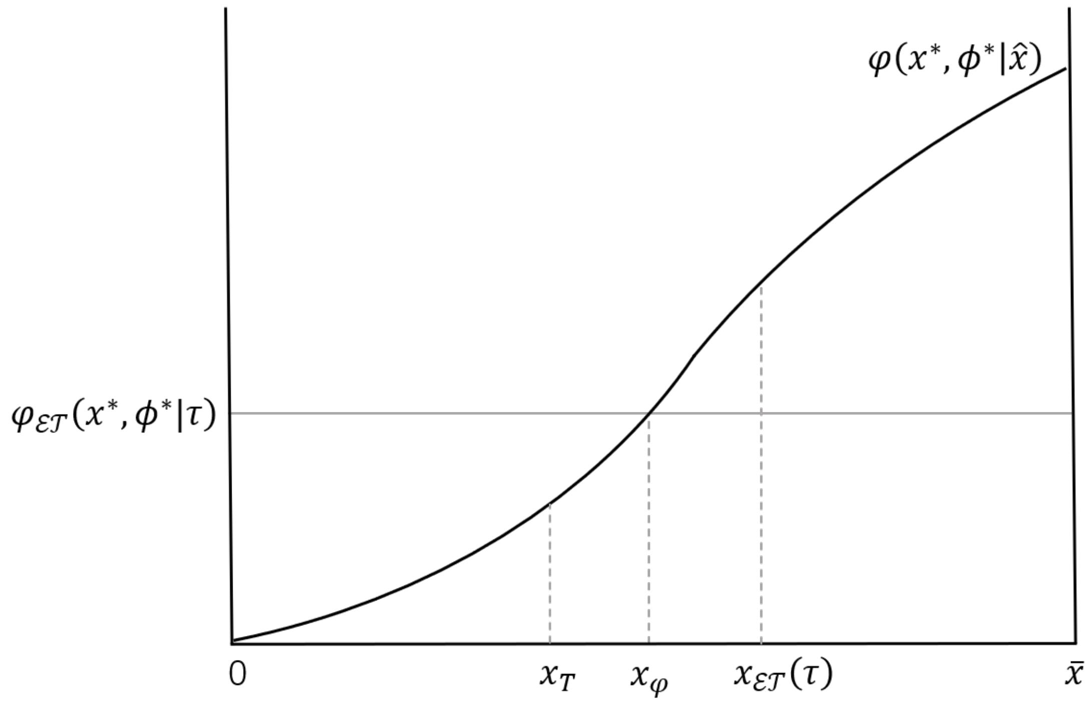
The economy has the same unemployment rate under the preexisting emission tax policy and the intensity standard at $\hat{x} = x_T$. According to Corollary 1, $u^{*\prime}(T) > 0$. By the definition of x_T, the flow costs are identical between the preexisting $\mathcal{ET}(\tau)$ and $\mathcal{IS}(x_T)$. Hence, the unemployment rate is the same under the two policies.

Meanwhile, the intensity standard $\mathcal{IS}(x_T)$ provides a better environmental quality than the preexisting emission tax policy. According to Corollary 1, $\phi^{*\prime}(T) < 0$. While the two policies share an identical flow cost, they share an identical proportion of the polluting sector and thus an identical level of emission along its extensive margin. As shown above, the unique x_T is less than $x_{\mathcal{ET}}(\tau)$: the preexisting emission tax policy incents each dirty-good job position to abate less than $\mathcal{IS}(x_T)$. Hence, the emission intensity is lower under $\mathcal{IS}(x_T)$ than the preexisting emission tax policy through a smaller intensive margin of emission.

Therefore, we can conclude that given any emission tax rate $\tau > 0$, there always exists a corresponding standard x_T such that the substitution of $\mathcal{IS}(x_T)$ for the preexisting $\mathcal{ET}(\tau)$ will improve the environmental quality without increasing unemployment. Nevertheless, $\mathcal{IS}(x_T)$ is not the only intensity standard policy that help the economy achieve the two goals. In what follows, we will uncover a range of standards that can achieve the two goals with the aid of another two critical emission levels.

If such a range of standards exists, these standards are larger than x_T. By the definition of x_T, the flow costs are identical between $\mathcal{IS}(x_T)$ and the preexisting $\mathcal{ET}(\tau)$. Since the abatement cost decreases with an emission level, the flow cost of an intensity standard policy decreases with $\hat{x}$. Hence, the $\mathcal{IS}(\hat{x})$ incurs a higher flow cost for all $\hat{x} < x_T$ but a lower flow cost for $\hat{x} > x_T$ than the preexisting $\mathcal{ET}(\tau)$. As implied by Corollary 1, the substitution of $\mathcal{IS}(\hat{x})$ for the preexisting $\mathcal{ET}(\tau)$ will increase unemployment for $\hat{x} < x_T$ and will increase employment for $\hat{x} > x_T$. Hence, if a policy shift to an intensity standard

Figure 6: The Environmental Quality under Intensity Standards and Emission Taxes



Notes: This graph shows that the emission intensity is a strictly increasing function of the cap level $\hat{x}$ under $\mathcal{IS}(\hat{x})$. It is a graphical presentation of the existence and uniqueness of x_φ between x_T and $x_{\mathcal{ET}}(\tau)$.

can break the employment-environment tradeoff, the corresponding $\hat{x}$ is no less than x_T.

Under $\mathcal{IS}(\hat{x})$, the emission intensity strictly increases with $\hat{x}$. Notice that the optimal emission level equals $\hat{x}$. When $\hat{x}$ increases, the intensive margin of emission increases. Meanwhile, a higher $\hat{x}$ incurs a lower abatement cost and thus flow cost. As implied by Corollary 1, the extensive margin of emission increases with $\hat{x}$. Hence, we can conclude that the emission intensity increases with $\hat{x}$ through both margins of emission as shown in Figure 6.

The second critical level is $x_{\mathcal{ET}}(\tau)$. When $\hat{x} = x_{\mathcal{ET}}(\tau)$, the intensity standard policy and the preexisting emission tax policy incent each dirty-good job position to abate at the same level: both share the same emission level along its intensive margin. As explained above, an economy has a higher fraction of the polluting sector under $\mathcal{IS}(x_{\mathcal{ET}}(\tau))$ than the preexisting emission tax policy because $\mathcal{IS}(x_{\mathcal{ET}}(\tau))$ imposes a lower additional flow cost than the preexisting emission tax policy on each dirty-good job position. As a result, the emission intensity is higher under $\mathcal{IS}(x_{\mathcal{ET}}(\tau))$ than the preexisting $\mathcal{ET}(\tau)$.

Figure 6 is a graphical presentation of an emission intensity under two types of policies. The horizontal line presents the emission intensity under the preexisting emission tax policy. The emission intensity of the intensity standard at $\hat{x} = x_T$ is lower than that of the preexisting emission tax policy, whereas the emission intensity of the intensity standard is above the horizontal line at $\hat{x} = x_{\mathcal{ET}}(\tau)$. By the intermediate value theorem, there must exist at least one standard x_φ, the third critical emission level in this analysis, such that both the intensity standard and the preexisting emission tax policy result in the same emission intensity. Since the emission intensity strictly increases with $\hat{x}$, x_φ is unique. For all $\hat{x} \leq x_\varphi$, the substitution of $\mathcal{IS}(\hat{x})$ for the preexisting $\mathcal{ET}(\tau)$ does not worsen the environmental quality.

In sum, a policy shift to $\mathcal{IS}(\hat{x})$ can avoid the employment-environment tradeoff for all $\hat{x} \in [x_T, x_\varphi]$. When the standard $\hat{x}$ is set below x_T, the shift is so stringent that the abatement cost of $\mathcal{IS}(\hat{x})$ will exceed the total additional cost from abatement and emission tax payment incurred by the preexisting $\mathcal{ET}(\tau)$. The higher additional cost discourages the creation of vacancies in the polluting sector. As a result, a policy shift from the preexisting $\mathcal{ET}(\tau)$ to $\mathcal{IS}(\hat{x})$ will worsen unemployment for all $\hat{x} < x_T$.

In contrast, the substitution of $\mathcal{IS}(\hat{x})$ will deteriorate the environmental quality for all $\hat{x} > x_\varphi$. When the standard $\hat{x}$ is set between x_φ and $x_{\mathcal{ET}}(\tau)$, a policy shift to $\mathcal{IS}(\hat{x})$ will cut the additional flow cost. Hence, the policy shift will increase the extensive margin of emission. Since $\hat{x}$ is below $x_{\mathcal{ET}}(\tau)$, the shift will decrease the intensive margin of emission. Overall, the emission intensity will increase. When the standard is above $x_{\mathcal{ET}}(\tau)$, a policy shift to $\mathcal{IS}(\hat{x})$ will increase both margins of emission. Hence, the substitution of $\mathcal{IS}(\hat{x})$ for the preexisting emission tax policy will deteriorate the environmental quality for all $\hat{x} > x_\varphi$.

Only if $\hat{x} \in (x_T, x_\varphi)$ can an intensity standard yield a better employment opportunity and environmental quality than the preexisting emission tax policy. The following theorem summarizes the findings:

Theorem 5. *Given any emission tax rate $\tau \in \mathbb{R}_{++}$, there always exists a range of standards such that the substitution of an intensity standard for the preexisting emission tax policy can simultaneously enhance the employment opportunity and environmental quality.*

In what follows, we explore another policy question. While Theorem 5 suggests that policymakers can always find intensity standards that result in a better employment opportunity and environmental quality than any preexisting emission tax policy, does it exist a comparable theorem for the substitution for preexisting intensity standards? In other words, given an intensity standard, does it exist any emission tax rate such that a policy shift from the preexisting intensity standard to an emission tax policy can break the employment-environment tradeoff? Certainly, policymakers are interested in this question because variants of intensity standards have been introduced to many countries.

We begin with the introduction of a policy scenario. Suppose an economy has an intensity standard policy $\mathcal{IS}(\hat{x})$. That is, each job position is permitted to emit $\hat{x} \in [0, \bar{x})$ units of pollutants per A units of production. Each dirty-good job position will find it optimal to emit $\hat{x}$ units of pollutants to minimize an abatement cost. Thus, the policy imposes

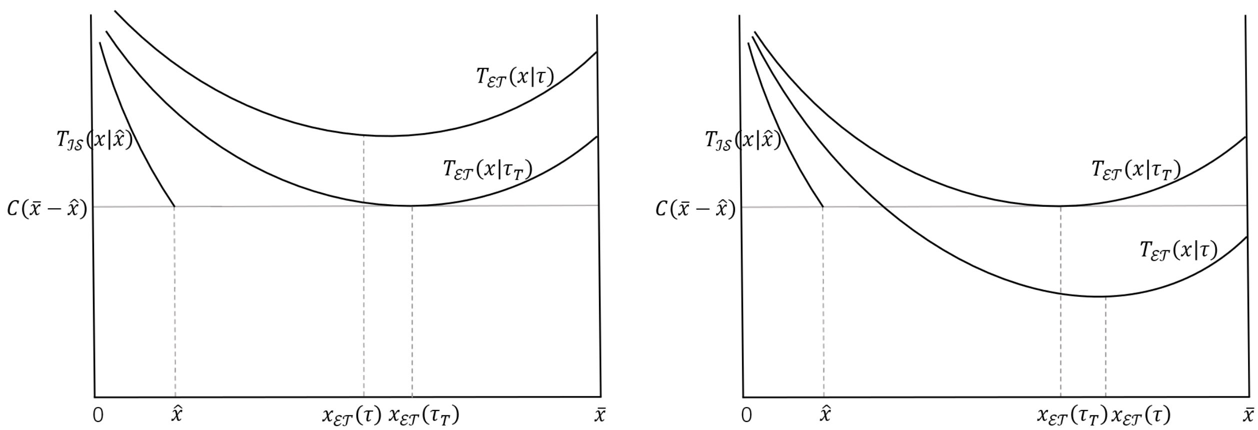


Figure 7: The Substitution of Emission Taxes for Intensity Standards

an additional flow cost equal to the abatement cost $T_{\mathcal{IS}}(\hat{x}) = C(\bar{x} - x_{\mathcal{IS}}(\hat{x}))$ on the job position.

We claim that given any standard $\hat{x} \in [0, \bar{x})$, there exists no emission tax rate $\tau \in \mathbb{R}_{++}$ such that the substitution of $\mathcal{ET}(\tau)$ for the preexisting intensity standard $\mathcal{IS}(\hat{x})$ can simultaneously enhance the natural and business environments. We will establish the claim with the aid of a critical emission level.

This critical emission level equates the additional flow costs incurred by an emission tax level and the preexisting intensity standard. We denote by τ_T the emission tax rate at which the associated emission tax policy incents each dirty-good job position to emit pollutants at the critical emission level $x_{\mathcal{ET}}(\tau_T)$.

We proceed to show that a unique emission tax rate τ_T exists. In general, the additional flow cost incurred by an emission tax policy is the sum of the emission tax payment and abatement cost. That is, $T_{\mathcal{ET}}(\tau) = \tau x + C(\bar{x} - x)$. When the tax rate is zero, each dirty good-job position is not required to pay any emission tax or abatement cost. That is, $T_{\mathcal{ET}}(0) = 0$. When the tax rate approaches positive infinity, either the tax payment is infinite (if it emits pollutants) or the abatement cost is infinite (if it emits no pollutants). As such, the flow cost tends to positive infinity. By the continuity of the flow cost function, the intermediate value theorem implies the existence of positive finite τ_T at which $T_{\mathcal{ET}}(\tau_T) = T_{\mathcal{IS}}(\hat{x})$. Since the flow cost function is strictly monotone under any emission tax policy, τ_T is unique.

A unique critical emission level $x_{\mathcal{ET}}(\tau_T)$ lies between $\hat{x}$ and $\bar{x}$. Since the optimal emission level strictly decreases with an emission tax rate (i.e., $x'_{\mathcal{ET}}(\tau) < 0$), the uniqueness of τ_T implies $x_{\mathcal{ET}}(\tau_T)$ is unique. Figure 7 demonstrates the optimal emission level of the preexisting intensity standard policy $\hat{x}$ and the corresponding critical emission level $x_{\mathcal{ET}}(\tau_T)$. When an intensity standard and an emission tax policy emit the same amount of pollutants, the emission tax policy imposes a higher additional flow cost on each dirty-good job position than the intensity standard does because of the emission tax payment. Since the flow costs are identical under $\mathcal{ET}(\tau_T)$ and $\mathcal{IS}(\hat{x})$, $x_{\mathcal{ET}}(\tau_T)$ and $\hat{x}$ are different. Only when $x_{\mathcal{ET}}(\tau_T) > \hat{x}$ will the additional flow costs be identical under the two policies.

For all $\tau > \tau_T$ (or equivalently $x_{\mathcal{ET}}(\tau) < x_{\mathcal{ET}}(\tau_T)$), the corresponding emission tax policy results in a higher unemployment rate than the preexisting intensity standard. By the definition of $x_{\mathcal{ET}}(\tau_T)$, the flow cost should be identical under $\mathcal{ET}(\tau_T)$ and the preexisting $\mathcal{IS}(\hat{x})$. A higher emission tax rate incents abatement, cuts emissions, and thus increases the additional flow cost. Therefore, for all $x_{\mathcal{ET}}(\tau) < x_{\mathcal{ET}}(\tau_T)$, the associated emission tax policy incurs a higher flow cost than the preexisting intensity standard as shown in the left panel of Figure 7. As implied by Corollary 1, a policy shift to such an emission tax policy will lead the economy to a higher unemployment rate. Hence, the substitution of the emission tax policy cannot break the employment-environment tradeoff for all associated emission level $x_{\mathcal{ET}}(\tau) < x_{\mathcal{ET}}(\tau_T)$.

There exists no emission tax rate $\tau \leq \tau_T$ (or equivalently no emission level $x_{\mathcal{ET}}(\tau) \geq x_{\mathcal{ET}}(\tau_T)$) such that a policy shift to the corresponding emission tax policy can improve the environmental quality and break the tradeoff. As discussed above and demonstrated in the right panel of Figure 7, $\hat{x} < x_{\mathcal{ET}}(\tau_T)$. Hence, the substitution of these emission tax policies will increase the intensive margin of emission. Also, these policies incur a higher flow cost than the preexisting intensity standard; hence, the substitution of these policies will cause the extensive margin of emission to rise. Hence, a policy shift from the preexisting intensity standard to any emission tax policy will increase the emission intensity for all $x_{\mathcal{ET}}(\tau) \geq x_{\mathcal{ET}}(\tau_T)$. The following theorem summarizes the findings:

Theorem 6. *Given any standard $\hat{x} \in [0, \bar{x})$, there exists no emission tax rate $\tau \in \mathbb{R}_{++}$ such that the substitution of an emission tax policy for the preexisting intensity standard can break the employment-environment tradeoff.*

5 Conclusion

Will the introduction of an emissions tax or intensity standard policy, or adjusting the existing emissions tax or intensity standard improve both the environmental quality and employment? This paper shows that under standard assumptions, introducing or adjusting the emission tax rate or intensity standard cannot avoid the employment-environment tradeoff, that is, the environmental quality improves at the expense of employment, and vice versa. However, there always exist intensity standards such that a policy shift from a preexisting emissions tax to the intensity standard improves both the environmental quality and employment. On the contrary, if there is a preexisting intensity standard policy in place, there exists no emissions tax rate such that a policy shift from intensity standard to emissions tax can improve both the environmental quality and employment.

For many countries, devising an appropriate climate-change policy is challenging, since the public is concerned of possible job losses from such policies. This paper synthesized some recent research on the tradeoff of environmental quality and employment (Bovenberg and van der Ploeg, 1996, 1998a,b; Ferris et al., 2014; Yamazaki, 2017; Hafstead et al., 2018; Hafstead and Williams, 2018; Yip, 2018; Castellanos and Heutel, 2019; Carbone et al., 2020; Yip, 2021). The presumption is that labor market friction is the fundamental determinant of the environment-employment tradeoff. This perspective can arguably help us understand the political feasibility of climate-change policies (Oates and Portney, 2003), and specifically, the superiority of intensity standard over emissions taxes (Gerlagh and Van der Zwaan, 2006; Fischer and Springborn, 2011; Li and Shi, 2011; Holland, 2012; Parry and Williams, 2012; Tombe and Winter, 2015).

For simplicity, our model abstracts a few aspects. For instance, worker productivity A and capital cost k are assumed homogeneous across sectors. If worker productivity is heterogeneous across sectors, the relative price of two intermediate goods will adjust according to the relative supply of the two goods. The conclusion of this paper will be largely unaffected. The analysis will be complicated enormously with heterogeneous capital cost. As shown in Acemoglu (2001), the model could yield multiple equilibria when capital costs are substantially different between sectors. Numerical analyses are required to determine the equilibrium in this case and we leave it for future research.

Finally, governments would be interested in designing more sophisticated policies to try to break the environment-employment tradeoff. For example, in the current analysis, the emissions tax revenues are abstracted from the labor market. Nevertheless, these revenues could be used to create jobs or subsidize job search, and analytical work that can reveal the channels and conditions for revenue recycling to break the environment-employment trade and inform modelling or policy choices along this line is an area for fruitful future research.

6 Appendix: Proof

6.1 Proof of Proposition 1

We show that a unique ϕ^* exists. Using the two zero-profit conditions (14) and (15), the revenue differential between jobs in the two sectors $\Lambda(\phi)$ is equal to the cost differential as follows:

$$\begin{aligned} \Lambda(\phi) &\equiv p_d(\phi)A - p_c(\phi)A \\ &= C(\bar{x} - x^*). \end{aligned}$$

In the absence of climate-change policies, job positions have no incentive to abate. As such, the cost differential becomes zero, implying that $p_d = p_c$ in the equilibrium.

Using the steady-state price equation (11), one can show that the revenue differential decreases with ϕ (i.e., $\Lambda'(\phi) < 0$). When ϕ tends to zero, p_d and thus the revenue differential approaches infinity. Similarly, when ϕ tends to one, p_d and thus the revenue differential approaches negative infinity. That is, $\lim_{\phi \to 0} \Lambda(\phi) = \infty$ and $\lim_{\phi \to 1} \Lambda(\phi) = -\infty$.

We will show a more general case scenario in which the cost differential is nonzero. Without loss of generality, we assume that $V = C(\bar{x} - x^*)$ is finite.

Since $\lim_{\phi \to 0} \Lambda(\phi) = \infty$, $\lim_{\phi \to 1} \Lambda(\phi) = -\infty$, and $\Lambda(\phi)$ is continuous on $(0, 1)$, there must exist at least one $\phi^* \in (0, 1)$ such that $\Lambda(\phi^*) = V$. Since $\Lambda'(\phi) < 0$ and the V is independent of ϕ, the $\phi^* \in (0, 1)$ is unique. Given the unique ϕ^*, the unique $p_d(\phi^*)$ and $p_c(\phi^*)$ are pinned down by equation (11).

Lastly, we show that a unique θ^* exists. When θ tends to zero, the R.H.S. of equation (14) approaches positive infinity because of $\lim_{\theta \to 0} q(\theta) = \infty$. When θ tends to positive infinity, its R.H.S. approaches negative infinity because of $\lim_{\theta \to \infty} q(\theta) = 0$ and $\lim_{\theta \to \infty} \theta q(\theta) = \infty$. As the L.H.S. is a positive constant, the intermediate value theorem ensures that there exists at least one $\theta^* > 0$ such that equation (14) is satisfied. Since the R.H.S. of equation (14) strictly decreases with θ, θ^* is unique. Substituting the unique θ^* into equation (10) yields the unique steady state u^* because u strictly decreases with θ. Given that x^*, ϕ^*, $p_d(\phi^*)$, $p_c(\phi^*)$, θ^*, and u^* are unique, it is straightforward to complete the rest of the proof.

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