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Emission Credit Trading and Regional Inequalities

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Emission Credit Trading and Regional Inequalities[*]

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Abstract

This paper examines how regional inequalities are affected by emission controls via credit trading and availability of absorption sources. We assume that homogeneous goods are costly traded without emission controls and that the rural areas have an advantage in terms of the availability of absorption sources. We especially focus on the long-term effects of firm relocation. Our two key findings are as follows. First, in the case where an emission control scheme is implemented without allowing for offsetting emissions with carbon absorption sources (carbon sinks), strengthening the emission controls drives firms to relocate from rural areas to urban areas, in the case that wage levels remain unchanged in both areas. As a result, regional inequalities in terms of both the number of firms and relative public welfare are enlarged by emission controls. Our second finding shows that in the case in which the emission control scheme allows for emissions-absorption offsetting, strengthening emission controls has mixed effects on the relative welfare of rural areas. Numerical simulations show that when the costs associated with transporting differentiated goods are relatively low, the introduction of emission controls with an offsetting system results in greater inequality across regions compared with introducing emission controls without such offsetting.

Keywords: Emission credit trading; Regional inequalities; Absorption sources; Firm relocation

JEL classification: Q5, R3

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1 Introduction

Developed countries are required to reduce the emission of greenhouse gas (GHG) to their targets agreed on in the Kyoto Protocol. For this objective, each country tries (or considers) introducing emissions trading schemes at domestic level. Meanwhile, Kyoto Parties can use land use, land use change, and forestry (LULUCF) in meeting their targets. Forest management, cropland management, grazing land management, and revegetation are all eligible LULUCF activities under the Protocol. Specifically, developed countries are given additional emission credit as Removal Unit (RMU) according to their supply of absorption sources of GHG.

There is no doubt that such emission controls affect a national economy. For example, Kuik and Mulder (2004) examine how alternative schemes of domestic emissions trading influence emissions reduction and macroeconomic costs in the Netherland. Linn (2010) examines the effect of cap-and-trade programs on profits of electric power company and found that Nitrogen Oxides Budget Trading Program reduced expected profits by as much as \$25 billion. However, to the best of our knowledge, there are no studies about the effect of emission controls on *regional inequalities* in a nation.

In the present paper, we theoretically examine how regional inequalities are affected by emission controls with credit trading and/or supply of absorption sources. Especially, we focus on a long-run effect, namely, the effect of *firm relocation*. Whether firm relocation is considered or not is essential for results. For example, if emission credit is given rural areas according to their supply of absorption sources, they become rich because of credit revenue, and, thus, an inequality between the urban and the rural is reduced in the short-run. However, it is not necessarily true if we consider firm relocation, since it changes the market accessibility in each area, which influences the welfare via consumer prices.

For focusing on firm relocation, we rely on the model used in the fields of New Trade Theory (NTT) and New Economic Geography (NEG) (e.g., Krugman, 1980; Fujita et al., 1999; Baldwin et al., 2003). Specifically, we take into account increasing returns to scale (IRS) in manufacturing and endogenous creation of firms based on the two-region model of Helpman and Krugman (1985). In the model, number of firms is determined by the interaction between firms producing differentiated varieties under monopolistic competition and workers with love for variety (Dixit and Stiglitz, 1977). There is one more (agricultural) sector, characterized by constant returns to scale (CRS), perfect competition, and homogeneity of the good. A few papers investigate environmental policies using the NEG framework (Pfluger, 2001; Venables, 2001; Zeng and Zhao, 2009; Ishikawa and Okubo, 2009). However, they focus on international relocation of firms reacting environmental damages and/or policies, and do not analyze regional inequalities at domestic level, which could be affected by environmental policies.

Most NTT or NEG studies including the above all papers suppose an unrealistic assumption. Specifically, the manufacturing good is assumed to be costly tradable while the homogeneous good is assumed to be freely traded. Wages in two regions are equalized by the assumption so that the general equilibrium analysis is quite simplified. However, it is criticized by some authors (e.g., Davis, 1998) for its odds with reality. In order to avoid such a criticism, we employ the model of Helpman and Krugman (1985) with trade costs of homogeneous good (Davis, 1998; Takatsuka and Zeng, 2009). As a result, trade costs of the homogeneous good are shown to be essential for our results.

Assuming that the homogeneous good is costly traded without emission controls and the smaller region has an advantage for supply of absorption sources, we find the following two main results. First, in the case of controls without supply of absorption sources, a severer emission control necessarily moves more firms to the larger region while wages are unchanged. As a result, regional inequalities in terms of both firm share and relative welfare are *enlarged* by controls. Second, in the case of controls with supply of absorption sources, the effect of controls on the relative welfare is ambiguous. Numerical simulations show that the relative welfare of the larger region could be increased by controls for a small manufacturing trade cost.

2 The model

The economy consists of two regions (N and S), two sectors (manufacturing and agriculture), and one factor (labor). There are L^w workers in the economy, and each of them owns one unit of labor. Denote the amounts of labor in N as L, and the counterpart in S with an asterisk. Denote $\theta = L/L^w$. Assume that region N is larger so that $\theta \in (1/2, 1)$. Labor is mobile between sectors but immobile between regions.[1] Furthermore, we assume

[1] If we allow interregional mobility of workers in our framework, the full agglomeration in one region is the only possible equilibrium. A typical approach to avoid such a result is introducing immobile

that the amount of labor in each region is sufficiently large so that the agricultural good is produced in each region for any equilibria.

The manufacturing sector M consists of a continuum of product varieties, and it is characterized by increasing returns to scale (IRS), monopolistic competition, while the agricultural sector A produces a homogeneous good under constant returns to scale (CRS) and perfect competition.

Workers are assumed to hold the same preference, which is described by a Cobb-Douglas utility for the two types of goods with a CES subutility on the varieties of good M:

$$U = M^{\mu} A^{1-\mu}, \tag{1}$$

where

$$M \equiv \left[\int_0^{n^w} c(i)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}},$$

n^w is the number of varieties in the M sector, and $c(i)$ is the consumption of variety i. Parameter $\sigma > 1$ is the elasticity of substitution between any two varieties of good M, and $\mu \in (0,1)$ is the expenditure share on good M.

As in most related papers, we assume Samuelson's iceberg transport costs. Specifically, τ_M (resp. τ_A) units of the good M (resp. good A) must be shipped for one unit to reach the other region. We assume that $\tau_M \in (1, \infty)$ and $\tau_A \geq 1$ in the paper.

We introduce a greenhouse-gas (GHG) emission control and emission credit trading into the model as follows. The M sector emits GHGs to produce varieties. Specifically, firms necessarily emit one unit of GHGs for producing one unit of variety. In order to satisfy international environmental agreements, the national government must control the total emission in the country to be under $\overline{X}$. For the purpose, the government introduces $\overline{X}$ units of emission credit (i.e., emission permit), one unit of which must be purchased by firms for their production of one unit of variety. Emission credit is traded in a competitive market. The government is located in N. We assume that the

agricultural workers to the model (Krugman, 1991). However, the approach does not allow inter-sector mobility of workers. As discussed below, a carbon-offset program induces workers to move from the manufacturing sector to the agricultural sector, which is not described by the model with immobility between sectors.

government expends its credit revenue on employing labor, which is used for its activities (e.g., management of emission credit trading, the carbon-offset program, and other policies for global climate change) and does not influence individual's utility. The reasons for assuming this is as follows. First, it is realistic to some extent. For example, in the third period (2013-2020) of EUETS, at least 50% of credit revenue promises to be used for measures against global climate change and energy policies (Morotomi, 2010, p.185) rather than some redistribution policies directly affecting welfare. Second, our setting gives a benchmark case. If this benchmark case brings an unfavorable result on inequalities, we could conclude that some portion of credit revenue should be used for reducing inequalities. Third, as shown below, we obtain some analytical and clear-cut results by this assumption.

We normalize the price of good A in S as $p_A^* = 1$ and denote the price of good A in N as p_A. In the agricultural production, one unit of labor produces one unit of good A. Thus, the wages in N and S are

$$w = p_A,\ w^* = p_A^* = 1, \tag{2}$$

respectively. Since wage is the only income of workers, the total expenditure in two regions are

$$E = w\theta L^w, \quad E^* = w^*(1-\theta)L^w, \tag{3}$$

respectively.

Each firm in the M sector needs a fixed cost of f unit of labor, and marginal costs of m units of labor and one unit of emission credit. Therefore, the total costs of producing x units of manufactured varieties are, respectively,

$$c(x) = fw + \mathrm{MC}x, \quad c^*(x) = fw^* + \mathrm{MC}^*x, \tag{4}$$

where

$$\mathrm{MC} = mw + q, \quad \mathrm{MC}^* = mw^* + q, \tag{5}$$

and where q is the price of emission credit.

Let p be the price of a manufacturing variety in N made in N, p^* be the price of a variety in S made in S, $\bar{p}$ be the price of a variety in N made in S, and $\bar{p}^*$ be the price of a variety in S made in N.[2] Then the monopolistic competition framework of Dixit and Stiglitz (1977) implies

$$p = \frac{\text{MC}\sigma}{\sigma - 1}, \quad p^* = \frac{\text{MC}^*\sigma}{\sigma - 1}, \quad \bar{p} = \frac{\text{MC}^*\sigma}{\sigma - 1}\tau_M, \quad \bar{p}^* = \frac{\text{MC}\sigma}{\sigma - 1}\tau_M. \tag{6}$$

From (1), the demands (plus iceberg costs) of each variety produced in N and S are

$$d_M = \mu\frac{p^{-\sigma}}{P^{1-\sigma}}E + \tau_M\mu\frac{(\bar{p}^*)^{-\sigma}}{(P^*)^{1-\sigma}}E^*, \; d_M^* = \mu\frac{(p^*)^{-\sigma}}{(P^*)^{1-\sigma}}E^* + \tau_M\mu\frac{\bar{p}^{-\sigma}}{P^{1-\sigma}}E, \tag{7}$$

respectively, where P and P^* are the manufacturing price indices defined by

$$P = \left[np^{1-\sigma} + n^*(\bar{p})^{1-\sigma}\right]^{\frac{1}{1-\sigma}}, \quad P^* = \left[n(\bar{p}^*)^{1-\sigma} + n^*(p^*)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}, \tag{8}$$

and n and n^* are numbers of firms in N and S. On the other hand, from (1), the demands of good A in N and S are

$$d_A = \frac{(1-\mu)E}{p_A}, \quad d_A^* = (1-\mu)E^*, \tag{9}$$

respectively.

In the model, free entry and exit of firms are assumed so that firms have zero profit. The output and the labor input of each firm are, therefore,

$$x = \frac{f(\sigma-1)w}{\text{MC}}, \; x^* = \frac{f(\sigma-1)w^*}{\text{MC}^*}, \tag{10}$$

$$l = f + mx, \; l^* = f + mx^*, \tag{11}$$

respectively. From (3), (7), (8), and (10), the market-clearing condition for varieties of good M produced in N and S are

$$\mu p^{-\sigma}\left[\frac{\theta w L^w}{np^{1-\sigma} + n^*(p^*)^{1-\sigma}\phi_M} + \frac{(1-\theta)w^*L^w\phi_M}{n^*(p^*)^{1-\sigma} + np^{1-\sigma}\phi_M}\right] = \frac{f(\sigma-1)w}{\text{MC}},$$

$$\mu(p^*)^{-\sigma}\left[\frac{(1-\theta)w^*L^w}{n^*(p^*)^{1-\sigma} + np^{1-\sigma}\phi_M} + \frac{\theta w L^w\phi_M}{np^{1-\sigma} + n^*(p^*)^{1-\sigma}\phi_M}\right] = \frac{f(\sigma-1)w^*}{\text{MC}^*},$$

[2] Because of symmetry among varieties, this price is independent of the variety name.

respectively, where $\phi_M \equiv \tau_M^{1-\sigma}$ is the trade freeness of good M. From (6), these equations could be rewritten as

$$\frac{\mu}{\sigma}\left[\frac{\theta L^w}{n+n^*\left(\frac{\mathrm{MC}^*}{\mathrm{MC}}\right)^{1-\sigma}\phi_M}+\frac{(1-\theta)\frac{w^*}{w}L^w\phi_M}{n^*\left(\frac{\mathrm{MC}^*}{\mathrm{MC}}\right)^{1-\sigma}+n\phi_M}\right]=f, \tag{12}$$

$$\frac{\mu}{\sigma}\left[\frac{\theta\frac{w}{w^*}L^w\phi_M}{n\left(\frac{\mathrm{MC}}{\mathrm{MC}^*}\right)^{1-\sigma}+n^*\phi_M}+\frac{(1-\theta)L^w}{n^*+n\left(\frac{\mathrm{MC}}{\mathrm{MC}^*}\right)^{1-\sigma}\phi_M}\right]=f. \tag{13}$$

It is noteworthy that if firms fully agglomerate in region N (resp. S), only (12) (resp. (13)) holds.

If the emission control is binding (i.e., $\overline{X}$ is less than the total emission without controls), the market-clearing condition for emission credit is

$$\overline{X}=nx+n^*x^*. \tag{14}$$

Finally, the indirect utilities of workers in N and S are

$$V=\frac{w}{p_A^{1-\mu}P^\mu},\ V^*=\frac{w^*}{(P^*)^\mu}, \tag{15}$$

respectively.

3 Equilibrium without controls

In the case without emission controls (or $\overline{X}$ is sufficiently large, and, thus, $q=0$), our model is equivalent to the model of Helpman and Krugman (1985, Section 10.4) with trade costs of good A, which is first analyzed by Davis (1998). Takatsuka and Zeng (2009, Section 2) reexamine the model and find the following fact (their Proposition 1):

Proposition 1 *(Takatsuka and Zeng, 2009). There is a threshold value $\widetilde{\tau}_A < \tau_M^{\frac{\sigma-1}{\sigma}}$ of the agricultural transport costs so that*
(i) good A is exported from S to N if $\tau_A<\widetilde{\tau}_A$; otherwise, good A is not traded;
(ii) it holds that $n/(n+n^*)\geq\theta$, where the equality holds only for $\tau_A\geq\widetilde{\tau}_A$.

By Proposition 1 (i),[3] we have

$$p_A = \tau_A \text{ for } \tau_A < \widetilde{\tau}_A, \tag{16}$$

$$p_A = \widetilde{\tau}_A \text{ for } \tau_A \geq \widetilde{\tau}_A. \tag{17}$$

Therefore, the equilibrium values $(w, w^*, \text{MC}, \text{MC}^*, x, x^*, l, l^*, n, n^*, p_A)$ are determined by (2), (5), (10), (11), (12), (13), and (16) (or (17)). Proposition 1 (ii) suggests that the "home market effect" (Krugman, 1980; Helpman and Krugman, 1985) appears if and only if $\tau_A < \widetilde{\tau}_A$.

Using this proposition, we derive the following result on the welfare:

Proposition 2 *In the case without emission controls, the welfare in N is higher than that in S.*

Proof. From (2), (5), (6), (8), (15), and the fact that $q = 0$, we have

$$V > V^* \Leftrightarrow nw^{1-\sigma}\left(1 - \phi_M w^{1-\sigma}\right) > n^*\left(w^{1-\sigma} - \phi_M\right). \tag{18}$$

It is sufficient to prove that the above inequality holds. From (2), (16), and (17), it holds that $w = \tau_A$ if good A is tradable; otherwise, $w = \widetilde{\tau}_A$. In both cases, we have $w < \tau_M^{\frac{\sigma-1}{\sigma}} < \tau_M$, which implies $w^{1-\sigma} > \phi_M > \phi_M w^{1-\sigma}$. Therefore, we have

$$\frac{n}{n^*} > 1 > \frac{w^{1-\sigma} - \phi_M}{w^{1-\sigma} - \phi_M (w^{1-\sigma})^2} = \frac{w^{1-\sigma} - \phi_M}{w^{1-\sigma}\left(1 - \phi_M w^{1-\sigma}\right)}, \tag{19}$$

where the first inequality is from Proposition 1 (ii). Inequality (19) implies that (18) is true. ■

In summary, without emission controls, the larger region has a higher wage, a more-than-proportionate share of firms, and a higher level of welfare. In other words, the market equilibrium entails these *regional inequalities*.

In the following sections, we assume that $\tau_A < \widetilde{\tau}_A$ holds, i.e., region N is the importer of good A without controls, since such a trade pattern is popular in the real world.

[3] The threshold $\widetilde{\tau}_A$ is a unique solution of $F(\tau_A) \equiv (\tau_A^{1-\sigma} - \tau_A \phi_M)\theta - (\tau_A^\sigma - \phi_M)(1-\theta) = 0$. See Takatsuka and Zeng (2009, Appendix A).

Assumption 1 *It is assumed that $\tau_A < \widetilde{\tau}_A$ holds, i.e., region N is the importer of good A without controls.*

4 Effects of emission controls

In this section, we examine how emission controls effect on regional inequalities in the terms aforementioned. Before analyzing effects of controls, we derive some useful lemmas.

From (5), we know that w (resp. w^*) and MC (resp. MC*) are related each other. However, now treat them as if they were independent. Then, we have the following lemma:

Lemma 1 *Treat w (resp. w^*) and MC (resp. MC*) as if they were independent.*
(i) In the interior equilibrium, n (resp. n^*) decreases (resp. increases) with MC/MC* and w/w^*.
(ii) In the corner equilibrium with $n^* = 0$ (resp. $n = 0$), n (resp. n^*) decreases (resp. increases) with w/w^*, and is independent with MC/MC*.

Proof. (i) Equations (12) and (13) immediately derive

$$\frac{\theta w L^w}{n\mathrm{MC}^{1-\sigma} + n^* (\mathrm{MC}^*)^{1-\sigma} \phi_M} = \frac{f\sigma}{\mu} \frac{w\mathrm{MC}^{\sigma-1} - w^* (\mathrm{MC}^*)^{\sigma-1} \phi_M}{1-\phi_M^2}$$
$$\frac{(1-\theta) w^* L^w}{n^* (\mathrm{MC}^*)^{1-\sigma} + n\mathrm{MC}^{1-\sigma}\phi_M} = \frac{f\sigma}{\mu} \frac{w^* (\mathrm{MC}^*)^{\sigma-1} - w\mathrm{MC}^{\sigma-1}\phi_M}{1-\phi_M^2}.$$

Since the LHSs are positive, we obtain a necessary condition for the interior equilibrium:

$$1 - \frac{w^*}{w}\left(\frac{\mathrm{MC}^*}{\mathrm{MC}}\right)^{\sigma-1} \phi_M > 0 \tag{20}$$
$$1 - \frac{w}{w^*}\left(\frac{\mathrm{MC}}{\mathrm{MC}^*}\right)^{\sigma-1} \phi_M > 0 \tag{21}$$

In the interior equilibrium, n and n^* can be obtained from equations (12) and (13):

$$n = \frac{\mu L^w}{f\sigma}\left[\frac{\theta}{1-\frac{w^*}{w}\left(\frac{\mathrm{MC}^*}{\mathrm{MC}}\right)^{\sigma-1}\phi_M} - \left(\frac{\mathrm{MC}}{\mathrm{MC}^*}\right)^{\sigma-1} \frac{(1-\theta)\phi_M}{1-\frac{w}{w^*}\left(\frac{\mathrm{MC}}{\mathrm{MC}^*}\right)^{\sigma-1}\phi_M}\right], \tag{22}$$
$$n^* = \frac{\mu L^w}{f\sigma}\left[\frac{1-\theta}{1-\frac{w}{w^*}\left(\frac{\mathrm{MC}}{\mathrm{MC}^*}\right)^{\sigma-1}\phi_M} - \left(\frac{\mathrm{MC}^*}{\mathrm{MC}}\right)^{\sigma-1} \frac{\theta\phi_M}{1-\frac{w^*}{w}\left(\frac{\mathrm{MC}^*}{\mathrm{MC}}\right)^{\sigma-1}\phi_M}\right]. \tag{23}$$

From (20) and (21), we know that the denominators in (22) and (23) are positive. Noting this fact and treating w/w^* and $\mathrm{MC}/\mathrm{MC}^*$ as if they were independent, (22) and (23) immediately imply that n (resp. n^*) decreases (resp. increases) with w/w^* and $\mathrm{MC}/\mathrm{MC}^*$.

(ii) For the corner equilibrium with $n^* = 0$, we have

$$n = \frac{\mu L^w}{f\sigma}\left[\theta + (1-\theta)\frac{w^*}{w}\right] \tag{24}$$

from (12). Meanwhile, for the corner equilibrium with $n = 0$, we have

$$n^* = \frac{\mu L^w}{f\sigma}\left[\theta\frac{w}{w^*} + (1-\theta)\right] \tag{25}$$

from (13). The second result of the lemma is immediately obtained by these equations. ■

Clearly, a higher $\mathrm{MC}/\mathrm{MC}^*$ implies a negative effect on the manufacturing production in N, since it means a relatively higher marginal cost there, which results in a relatively higher price and less demand. On the other hand, w/w^* includes both positive and negative effects on the manufacturing production in N. A higher w/w^* means a higher wage income in N, which implies a positive effect since the market size is relatively larger there if other things being equal. However, it also means a relatively higher fixed cost in N, which is a negative effect. Lemma 1 claims that even if a higher w/w^* entails the positive effect, the negative effect necessarily dominates the positive one, and, thus, the number of firms in N decreases.

Next, concerning the effects of the emission credit price q on the total manufacturing production, the following lemma holds:

Lemma 2 *For fixed wages, the total manufacturing production $nx+n^*x^*$ strictly decreases in q.*

Proof. From (5) and (10), both x and x^* decrease in q. With (24) and (25), we know that $nx + n^*x^*$ decreases in q for a corner equilibrium. For an interior equilibrium, from (10), (22), and (23), we have

$$x\frac{\partial n}{\partial q} + x^*\frac{\partial n^*}{\partial q} = -m^2(w-w^*)^2\frac{\mu(\sigma-1)^2 L^w}{\sigma \mathrm{MC}\cdot\mathrm{MC}^*} \times$$
$$\left\{\frac{w^*\left(\frac{\mathrm{MC}^*}{\mathrm{MC}}\right)^{\sigma-1}\theta}{\left[1-\frac{w^*}{w}\left(\frac{\mathrm{MC}^*}{\mathrm{MC}}\right)^{\sigma-1}\phi_M\right]^2} + \frac{w\left(\frac{\mathrm{MC}}{\mathrm{MC}^*}\right)^{\sigma-1}(1-\theta)}{\left[1-\frac{w}{w^*}\left(\frac{\mathrm{MC}}{\mathrm{MC}^*}\right)^{\sigma-1}\phi_M\right]^2}\right\} \leq 0.$$

Thus, we have

$$\frac{\partial\left(nx+n^{*}x^{*}\right)}{\partial q}=\left(x\frac{\partial n}{\partial q}+x^{*}\frac{\partial n^{*}}{\partial q}\right)+\left(n\frac{\partial x}{\partial q}+n^{*}\frac{\partial x^{*}}{\partial q}\right)<0.$$

■

This lemma implies that a severer emission control is equivalent to a higher credit price for fixed wages. As we show later, the wages are unchanged even if the credit price rises under Assumption 1. Thus, in the rest part of this section, we consider the situation with a severer emission control as that with a higher credit price.

4.1 The case of costlessly tradable A

First, we examine the case that $\tau_A = 1$, i.e., good A is costlessly traded. Many existing studies (e.g., Venables, 2001; Zeng and Zhao, 2009; Ishikawa and Okubo, 2009) suppose this assumption for simplicity. However, this assumption is not only unrealistic (Davis, 1998) but also gives a very different result in contrast with the case that $\tau_A > 1$. This is because the free-trade of good A never generate wage differentials between two regions. In fact, if $\tau_A = 1(= w)$, by (2), (5), and (16), we have $w/w^* =$MC/MC$^* = 1$ with or without controls. Thus, by Lemma 1, we know that the number of firms in each region is unchanged by emission controls. On the other hand, emission controls increase manufacturing prices because of higher credit prices, and, thus, we know that welfare levels in both regions are decreased due to higher price indices. However, from (6) and (8), the relative price index P/P^* is expressed by

$$\frac{P}{P^{*}}=\left[\frac{n\left(\mathrm{MC}\right)^{1-\sigma}\phi_M+n^{*}\left(\mathrm{MC}^{*}\right)^{1-\sigma}}{n\left(\mathrm{MC}\right)^{1-\sigma}+n^{*}\left(\mathrm{MC}^{*}\right)^{1-\sigma}\phi_M}\right]^{\frac{1}{\sigma-1}}=\left[\frac{\frac{n}{n^{*}}\left(\frac{\mathrm{MC}}{\mathrm{MC}^{*}}\right)^{1-\sigma}\phi_M+1}{\frac{n}{n^{*}}\left(\frac{\mathrm{MC}}{\mathrm{MC}^{*}}\right)^{1-\sigma}+\phi_M}\right]^{\frac{1}{\sigma-1}}, \tag{26}$$

which remains a constant, and, thus, the relative welfare V/V^* is neither affected by emission controls. In summary, although emission controls increase manufacturing prices and decrease welfare levels, they do not change regional inequalities such as w/w^*, $n/(n+n^*)$, and V/V^*.

Proposition 3 *If $\tau_A = 1$, any emission controls do not change wages, numbers of firms, and the relative welfare.*

4.2 The case of costly tradable A

Next, we consider the case that $\tau_A \in (1, \widetilde{\tau}_A)$. Without controls, region N imports good A from S by the argument in Section 3. Thus, with a *marginal control*, N still imports good A. Thus, from (2), (5), and (16), we have

$$w = \tau_A,\ w^* = 1, \tag{27}$$

$$\mathrm{MC} = m\tau_A + q, \quad \mathrm{MC}^* = m + q. \tag{28}$$

These equations imply that w/w^* is not changed by the control, while $\mathrm{MC}/\mathrm{MC}^*$ decreases from τ_A to $(m\tau_A+q)/(m+q)$. Thus, by Lemma 1, n (resp. n^*) increases (resp. decreases) in the interior equilibrium, and both n and n^* are unchanged in the corner equilibrium with $n^* = 0$. On the other hand, it holds that

$$l^* = f + \frac{mf(\sigma-1)w^*}{\mathrm{MC}^*} \tag{29}$$

from (10) and (11). Thus, we know that l^* is decreased by the control since MC^* increases and w^* remains one. Therefore, we know that the export of good A from S to N

$$L^* - n^* l^* - (1-\mu)E^*. \tag{30}$$

increases, since both n^* and l^* decreases in the interior equilibrium and l^* decreases in the corner equilibrium. This confirms that, with *any levels of controls*, N imports good A and (27) and (28) hold, which also implies that w is still equal to τ_A.

Finally, from (26), the relative price index P/P^* is decreased by emission controls since $\mathrm{MC}/\mathrm{MC}^*$ decreases and n/n^* increases in the interior equilibrium and $\mathrm{MC}/\mathrm{MC}^*$ decreases in the corner equilibrium.. Therefore, from (15),

$$\frac{V}{V^*} = \frac{(w/P)^\mu}{(w^*/P^*)^\mu} = \left(\frac{\tau_A P^*}{P}\right)^\mu$$

must increase.

Summing up, we have the following proposition:

Proposition 4 *Assume that $\tau_A \in (1, \widetilde{\tau}_A)$. Then, emission controls increase the relative welfare in N (V/V^*), while the wages are unchanged. Furthermore,* *(i) in the interior equilibrium, n (resp. n^*) is increased (resp. decreased), and*

(ii) in the corner equilibrium, both n and n^* are unchanged.

This proposition states that although *nominal* wages are not changed by controls, *the real wage inequality is increased* in terms of welfare ratio V/V^*. The reason is simple. Firm distribution is determined by the balance of the *market-access effect* and the *production-cost effect* (e.g., Amiti, 1998; Laussel and Paul, 2007). In other words, in a larger region, the larger market attracts more firms while the higher production costs work against firm location. Emission controls do not change the market-access effect since nominal wages are unaffected, while they influence the production-cost effect. Specifically, the marginal cost in S is relatively increased, which implies that the *advantage of a small region is weakened*. This is because the identical charge (purchase of credit) is required for an additional production in both regions with different marginal costs (wages). Therefore, more firms agglomerate in the large region, which decreases the price index in N relatively. The price index in N is also relatively lowered by decreasing of MC/MC*, since it implies that the manufacturing price in N is relatively lowered. Therefore, emission controls increase the welfare in N relatively. In the corner equilibrium, firm location is unchanged but MC/MC* decreases. Thus, the relative welfare in N is increased again.

5 Supply of absorption sources

The previous section clarifies that if good A is costly traded without controls, introducing emission controls must increase regional inequalities in terms of firm share $n/(n+n^*)$ and relative welfare V/V^*. In this section, we examine the case of controls *with supply of absorption sources*.

Here, we assume that the A sector provides absorption sources of GHGs. For simplicity, we assume that the production of one unit of good A entails k (resp. k^*) units of absorption sources (net of supply costs) in N (resp. S).[4] In addition, we suppose that $k \leq k^*$ since

[4] In other words, we *exogenously* give the supply of homogeneous good and absorption sources per worker in each region. However, our main message is *not changed* even if they are *endogenously* determined. Therefore, *regional inequality in terms of relative welfare could be enlarged even in comparison with the case of controls without supply of absorption sources*. This is because the carbon-offset program increases the relative income in region S while it induces workers to move from the manufacturing sector to the agricultural sector, which lowers the market access.

there are usually rich natural resources (e.g. forestry) for absorption of GHGs in periphery regions. One unit of GHGs is absorbed by one unit of absorption sources. Thus, each worker in the A sector obtain k (resp. k^*) units of emission credit in N (resp. S), and, in this case, we have

$$w = p_A + kq,\ w^* = 1 + k^*q, \tag{31}$$

instead of (2). In addition, the market-clearing condition for emission credit (14) is replaced by

$$\overline{X} + ks_A + k^*s_A^* = nx + n^*x^*, \tag{32}$$

where s_A is the agricultural production in N.

If emission controls are moderate (i.e., $\overline{X}$ is large) and/or supply of absorption sources is large, q could be zero. In such a case, nothing could be changed by controls. If emission controls are binding, i.e., $q > 0$ holds, and region N still imports good A from S, we have

$$w = \tau_A + kq,\ w^* = 1 + k^*q, \tag{33}$$

$$\mathrm{MC} = m\tau_A + (mk+1)q, \quad \mathrm{MC}^* = m + (mk^*+1)q, \tag{34}$$

from (5), (16), and (31). Equation (33) implies that w/w^* is decreased from τ_A to $(\tau_A + kq)/(1 + k^*q)$ by the control. In addition, by (34), MC/MC* also decreases from τ_A to $(\tau_A + kq + q/m)/(1 + k^*q + q/m)$. Thus, by Lemma 1, n (resp. n^*) increases (resp. decreases) in the interior equilibrium, and n increases in the corner equilibrium with $n^* = 0$. This implies that the firm share of N $n/(n + n^*)$ increases.

There are some remarks. First, contrastive to the case of previous section, we do not know whether the relative welfare V/V^* is increased or decreased by controls. This is because the relative wage w/w^* is decreased since $k \leq k^*$. In other words, in region N, the firm share increases while the relative wage decreases, and, thus, whether the relative welfare increases or decreases depends on the balance of these two changes. Second, if emission controls are moderate, the supply of absorption sources reduces the firm share inequality in comparison with the case of controls without absorption sources. Typically, it holds when $q = 0$. However, third, if emission controls are severe, the supply of absorption sources might increase the firm share inequality in comparison with the case of controls without absorption sources. This is because, in the present case, not only MC/MC* but also w/w^* is decreased because of the credit revenue.

5.1 Numerical simulations

Figure 1 illustrates a simulation example of $\sigma = 5$, $\theta = 0.7$, $\mu = 0.4$, $m = 0.1$, $f = 0.1$, $L^w = 100$, $k = 0$, $k^* = 1$, $\tau_A = 1.02$. The four cases correspond to four τ_M values: (a) 1.44, (b) 1.33, (c) 1.22, (d) 1.075. Assumption 1 holds in this setting. Furthermore, region N always imports good A from S with supply of absorption sources in our simulation. Amount of GHG emission is depicted on the horizontal axis in all panels (100% = the case without controls), and the firm share of N ($n/(n+n^*)$) and the relative welfare (V/V^*) of N are on the vertical axis in left-side and right-side panels, respectively. The solid (resp. dotted) lines in graphs correspond to the case without (resp. with) supply of absorption sources.

[INSERT FIGURE 1 AROUND HERE]

These panels confirm Proposition 4. Without supply of absorption sources, a severer emission control necessarily brings a higher $n/(n+n^*)$ and a higher V/V^*. Furthermore, we observe that this tendency of firm relocation is strengthened by a lower τ_M. In fact, in Case (d) with the smallest τ_M, firms fully agglomerate in region N when controls make GHG emission less than 77% of the present. The reason is as follows. More firms locate in N under severer emission controls because the production cost becomes relatively lower there. If τ_M is small enough as in a free-trade economy, this tendency is significant since the production-cost effect becomes dominant. On the other hand, if τ_M is very large as in a closed economy, the market-access effect is dominant, and, thus, firms tend to disperse subject to the market sizes of two regions.

Next, turn to the case with supply of absorption sources. In the case, we also confirm some points discussed above. Firstly, when emission controls are moderate (i.e., GHG emission is large), both the firm share and the relative welfare are the same as in the case without controls. This is because the credit price is zero. Secondly, the firm share of N increases with the intensity of emission controls *more remarkably* than the case without absorption sources. This is because, as aforementioned, both MC/MC* and

w/w^* decreases because of the credit revenue for region S. In addition, the tendency is strengthened by a lower τ_M again. Thirdly, the relative welfare decreases in some case while the opposite holds in other cases. According to Figure 1, in Case (a) with the largest τ_M, the relative welfare monotonically decreases with the intensity of emission controls. In other words, regional inequality in terms of relative welfare is reduced in comparison with both the case without controls and the case with controls without supply of absorption sources. This is because increasing of the firm share of N is moderate for a larger τ_M, and, thus, decreasing of the relative wage of N dominantly influence the relative welfare. However, for a smaller τ_M, the balance of these two changes could be opposite. Specifically, in Case (b), the relative welfare is still lower than the case without absorption sources, but it increases with the intensity of emission controls for a range. In other words, although regional inequality in terms of relative welfare is reduced in comparison with the case of controls without supply of absorption sources, it is enlarged in comparison with the case without controls. Furthermore, in Cases (c) and (d), we observe that it could be enlarged even in comparison with the case of controls without supply of absorption sources. This is clearly because increasing of the firm share of N dominantly influences the relative welfare.

It should be noted that the government is supposed to expend its credit revenue on employing labor, which is used for its activities and does not influence individual's utility. As aforementioned, this setting gives a benchmark case. If this benchmark case unfavorably enlarges inequalities, some portion of credit revenue should be used for reducing inequalities.

6 Concluding remarks

This paper has examined how regional inequalities are affected by emission controls with credit trading and/or supply of absorption sources considering firm relocation. Assuming that the homogeneous good is costly traded without controls and the smaller region has an advantage for supply of absorption sources, we find the following two main results. First, in the case of controls without supply of absorption sources, a severer emission control necessarily moves more firms to the larger region while wages are unchanged. As a result, the relative welfare of N rises. In other words, regional inequalities in terms of both firm share and relative welfare are enlarged by controls. This is because the marginal cost in the smaller region is relatively increased because of the purchase of emission credit, which weakens the advantage of the region. Second, in the case of controls with supply of absorption sources, we expect that a severer control brings more firms in the larger region but the relative wage of N decreases. As a result, the effect of controls on the relative welfare is ambiguous. Numerical simulations show that the relative welfare of N is decreased by controls for a large manufacturing trade cost while it could be increased for a small manufacturing trade cost. This is because if the manufacturing trade costs are small enough as in a free-trade economy, the production-cost effect dominates the market-access effect, and, thus, firms significantly agglomerate in the larger region under the emission control.

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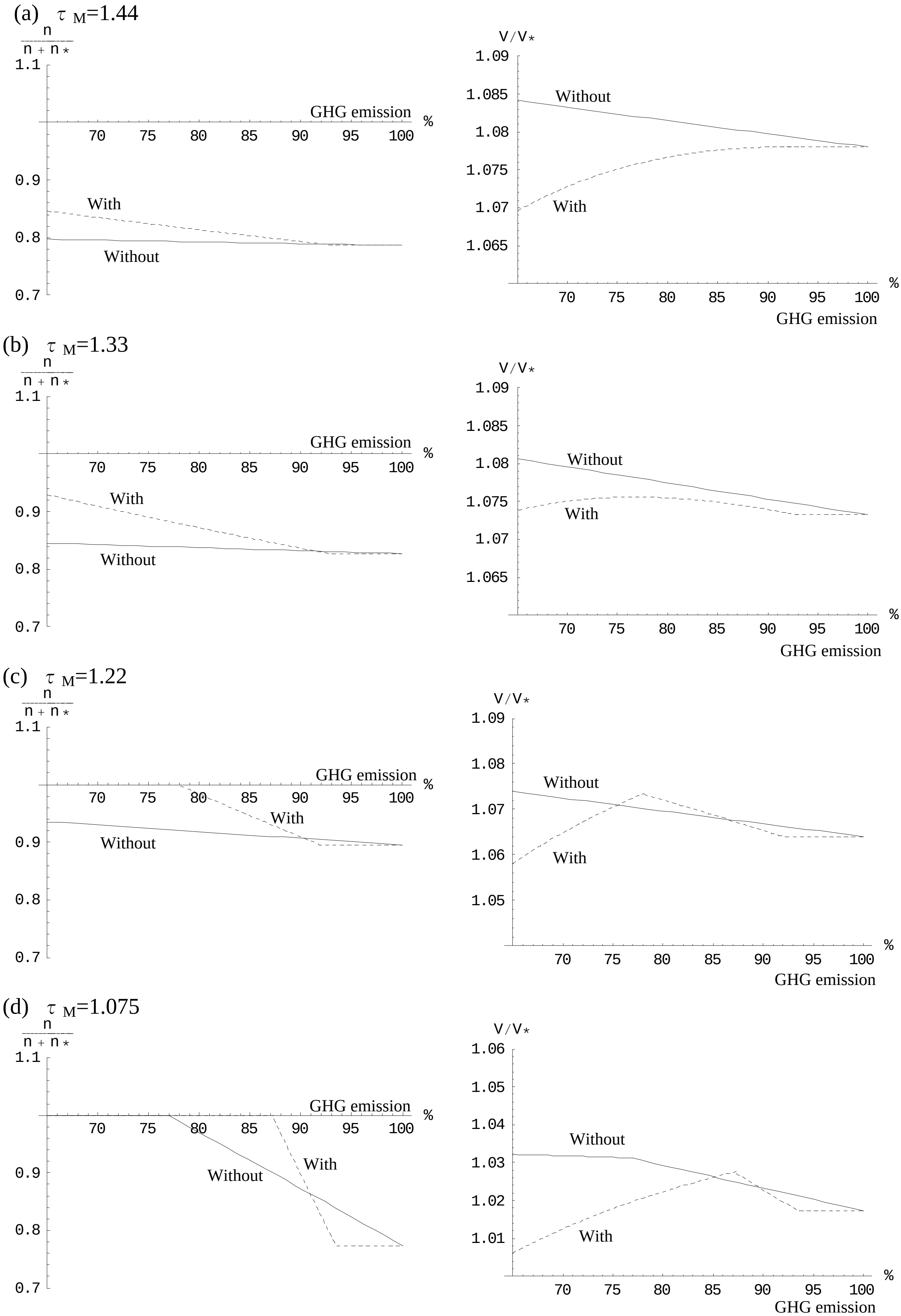

Figure 1. Regional Inequalities under the Emission Controls with or without Supply of Absorption Sources.