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Premit Trading and Credit Trading – A Comparative Static Analysis with Perfect and Imperfect Competition.

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A Comparative Static Analysis with Perfect and Imperfect Competition

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Abstract

This paper compares emissions trading based on an absolute cap, denoted permit trading, with a scheme based on relative standards, denoted credit trading, under both perfect and imperfect competition. I show that credit trading is an inefficient instrument and that the two schemes have a different impact on the regulated industry. Credit trading leads to higher total output, higher marginal abatement costs and a higher number of firms in the market than permit trading. Furthermore, under both schemes the total number of firms can both decrease and increase as a result of regulation. I find that under perfect competition, permit trading gives highest welfare, while under imperfect competition, credit trading mostly leads to higher welfare. With foreign competition however, credit trading is more likely to be chosen since this gives a better competitive position for firms.

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1 Introduction

In the economic literature, emissions trading is almost always equated with a system based on a ceiling or cap on total emissions. In such a scheme, the government agency determines a cap on total emissions and divides this in permits that are distributed in some way over the existing firms, after which the firms are allowed to trade the permits. Many of the US emissions trading schemes are of this type, with the SO_x trading scheme as a prime example. Also the EU greenhouse gas emissions allowances trading scheme, that is to start in 2005 is a cap and trade system.

Instead of using absolute standards as the basis, emissions trading can be based on relative standards. In this case, instead of putting a cap on total emissions, a cap is placed on emissions per unit of some input or on output. Firms are then allowed to sell credits when they can stay below the emission ceiling defined as the standard times the amount of input or output. Just as with permit trading, firms can be allowed to trade before the realization of emission reductions (see Boom and Nentjes (2003)). The lead trading program in the US is one example of emissions trading based on relative standards (see Svendsen (1998)). In 1982, the US Environmental Protection Agency limited the lead content in gasoline to 1.1 grams per gallon and tightened the standard in following years to 0.1 grams in 1986. Refineries that stayed below the standard could sell credits to other refineries. Another example is the Dutch NO_x emissions trading scheme that has started per 2004. In this scheme, a difference is made between combustion installations and process installations. The first emit NO_x as a result of the combustion of fuels. The standard for these installations is based on the amount of NO_x per gigajoule (GJ) fuel used, decreasing from 65 gram/GJ in 2004 to 50 g/GJ in 2010. Hence, combustion installations are faced with a relative input standard. Process installations however are regulated through a relative output standard determined as allowed NO_x emissions per unit of output that is different for different processes. Again, firms that stay below the standard are allowed to sell credits. In the following, emissions trading based on a cap on emissions will be denoted by permit trading, while emissions trading based on relative standards will be denoted as credit trading.

Besides using the schemes separately, they can be combined, both at the national and international level. An example at the national level is the case in the UK where a greenhouse gas permit trading scheme is combined with a credit trading scheme (DEFRA (2001) and DEFRA (2002)). In the Netherlands, a CO_2 emissions trading scheme has been proposed where the exporting sectors are regulated though a credit trading scheme, while the remaining sectors are regulated through permit trading (CO2 Trading Commission (2002)). Although the EU has opted for a permit trading scheme, combined trading could arise at the international level if other countries started credit trading schemes and trading of emission allowances was allowed internationally between the schemes.

In this paper, I will give an analysis of permit and credit trading discussing their performance under both perfect and imperfect competition. The analysis consists of two parts. In the first part, a very general partial equilibrium model will be developed. Here, both the short-run and long-run consequences of the two types of emissions trading are discussed and the effects on firm and total production, abatement costs, numbers of firms in the industry and welfare are given. However, some problems remain unresolved in the general model and therefore, a more specific model is developed in the second part. This model is used to generate some simulations that give further insight into the working of the two schemes. The specific model is especially useful for the case of imperfect competition. In the general model, the number of firms cannot be determined, while this factor has great influence on the outcome.

Credit trading has already received some attention. Boom (2001) was the first to give credit trading some thought. His analysis shows that output will be larger under credit trading than under permit trading (see also Boom and Nentjes (2003)). Fisher (2001) discusses several instruments, one of which is credit trading. In her, short-run model, marginal costs of production are constant in output and total emissions are given by a variable emissions rate times output. Fisher shows that credit trading can be seen as a tax on emissions equal to the credit price combined with a subsidy per unit of output equal to the average value of emissions embodied in output (credit price times the relative standard times output). Because of this, output will be larger under credit trading than is optimal. Furthermore, if the relative standard is set such that the credit price is equal to the Pigouvian tax rate, total emissions will be higher than the social optimum amount. Hence, to achieve the socially optimal pollution level a stricter standard has to be set, resulting in a higher credit price. Because of the assumption of constant marginal costs, the number of firms in the sector becomes irrelevant, which makes it impossible to analyze the effects on industry structure. Gielen et al. (2002) give a comparison of emissions trading based on a cap and that based on relative standards. They discuss the two systems in the framework of perfect competition in the goods market and discuss the linkage of the two schemes. Also Gielen et al. find that credit trading leads to lower product prices and higher marginal abatement costs than permit trading. They do give a long-run model of the problem, but only conclude that optimal firm size and the number of firms in the industry depend on the cost structure of the firms.

This paper differs from the ones discussed above by giving a more detailed analysis of the two emissions trading schemes. This gives the possibility to determine how all variables in the model change as a result of regulation and gives full insight in the differences between the schemes. Not only industry output is determined, but also firm output. The models presented in this paper also make it possible to discuss the impact of the two schemes on the number of firms in the industry. Furthermore, I analyze the systems under both perfect and imperfect competition. The effects of the two schemes are basically the same under both perfect and imperfect competition. However, under imperfect competition, production is lower than optimal and firms make a profit. This makes that the welfare implications of the two schemes may change compared to perfect competition. Also with imperfect competition, the number of firms is variable. As this paper shows, this factor has a large impact on the outcome due to the fact that market power is inversely related to the number of competitors in the market.

The paper is organized as follows. In the next section, a general model is presented of both perfect and imperfect competition. The effects of the two emissions trading schemes on variables such as output, product price and abatement costs are analyzed. Furthermore, the welfare performance of the instruments is discussed. In section 3 the more specific model is given. Several simulations are presented to give an insight into the working of the model and the two trading schemes. Some political considerations are given in Section 4. Finally, section 5 gives some conclusions.

2 A General Model

In this section, a general model of permit and credit trading is developed, which will be used to analyze the cases of perfect and imperfect competition. In all cases, it is assumed that the government wants to regulate the emissions E of a pollutant so that the total level does not exceed the limit L, where L is binding. The pollutant is emitted by an industry, consisting of n identical firms. Costs of production for a single firm are given by $C(q, E)$, where q gives the level of output. The properties of the cost function are $C_q > 0$, $C_{qq} \geq 0$, $C_{qE} \leq 0$, $C_E < 0$ and $C_{EE} \geq 0$. Inverse demand for the product is given by $p = p(nq)$.

2.1 Perfect Competition

With perfect competition, the number of firms in the market is large and no single firm has an influence on the product or emissions quota price. First, I will analyze optimal firm behavior in the short-run and then discuss the effects on the industry in the long-run.

Short run. In the short run entry and exit do not take place. Therefore, the number of firms in the sector is given. Because of this, it is possible that firms will receive a profit, or incur losses in the short run. The emissions standards set by the government are also fixed in the short run. For permit trading this makes no difference with the long run since the limit is by definition fixed in every period, but for credit trading there is a difference since the relative standard will differ with output. In all then, two variables, the price of the product and the quantity produced, must be determined in the short run. The supply function is determined by the first order condition for profit maximization, while demand is given by the inverse demand function.

With permit trading, each firm receives an initial amount of permits $\bar{E}$. The price of permits that arises in the market is denoted by R^p. The profit function of the firm is then given by

$$\pi = pq - C(q, E) - R^p(E - \bar{E})$$

We assume that the firm maximizes its profits. It will then choose its production and emission levels according to the following conditions

$$\frac{\partial \pi}{\partial q} = p - C_q = 0 \tag{1}$$

$$\frac{\partial \pi}{\partial q} = -C_E - R^p = 0 \tag{2}$$

The first condition says that marginal revenue, in this case price, should be equated with marginal costs of production. Since $C_{qE} < 0$, regulation gives an increase in production costs and therefore an increase in the product price. The optimal emission level is found by equating the marginal costs of emissions to the price of permits.

With credit trading, the scheme is not based on an absolute standard, but on a limit on emissions per unit of output. Let the relative target be given by $\bar{e}$. Total allowable emissions for the firm is then $\bar{e}q$ plus or minus the number of credits bought or sold respectively. Under these conditions, profits for the firm are given by

$$\pi = pq - C(q, E) - R^c(E - \bar{e}q)$$

where R^c is the market price for credits. The first order conditions for profit maximization are

$$\frac{\partial \pi}{\partial q} = p - C_q + R^c \bar{e} = 0 \tag{3}$$

$$\frac{\partial \pi}{\partial E} = -C_E - R^c = 0 \tag{4}$$

These can be combined to give

$$p = C_q + \bar{e} C_E$$

Since (4) holds for all firms, abatement costs will be equalized between firms. Hence, credit trading achieves an efficient distribution of the abatement burden across firms. However, as a comparison between (3) and (1) shows, the production levels under the two schemes will not be identical. With credit trading, the term $R\bar{e}$ makes that firms no longer equate marginal production costs to the price of the product, but to a lower level, indicating that total output will be higher and the product price lower under credit trading. The additional factor can be seen as an output subsidy (Fisher (2001)) since the firm is allowed to emit more when it produces more.

Long Run In the long run, the number of firms is variable and the government can change the standard set. Besides profit maximization, it is now required that firms remaining in the industry have zero profits. Furthermore, with credit trading, the government agency will adjust the relative standard, as production changes so as to achieve the absolute emission target L.

For permit trading, this implies that the long-run conditions for a firm are

$$p = C_q(q, E)$$
$$pq = C(q, E) + R^p E$$
$$-C_E(q, E) = R^p$$
$$nE = L$$

Note that the permits grandfathered to the firms, $\bar{E}$ do not appear in the conditions above. The reason is that the permits represent an opportunity cost to the firm. If the firm does not cover its emissions costs, it would be better off if it sold its permits and closed production.

With credit trading, changes in total output will affect the relative standard set by the government agency. However, with perfect competition, each firm is too small to have an effect on the standard set. Therefore, also in the long run, firms take $\bar{e}$ as given. The long-run conditions for credit trading then are

$$p = C_q(q, E) - \bar{e}C_E$$
$$pq = C(q, E) - R^c(E - \bar{E})$$
$$-C_E = R^c$$
$$nE = L$$

As a final condition for both schemes, the inverse demand function is given by

$$p = p(nq)$$

From the above, several points can be deduced. First of all, as already mentioned above, total output will be higher under credit trading than under permit trading. Since output is higher and the limit on total emissions is the same under both instruments, marginal costs of abatement must be higher under credit trading. To see this, recall that we have defined $C_{Eq} \leq 0$. This implies that as production is increased with emissions constant, production costs will increase. The result is that the emissions quota price will be higher under credit trading than under permit trading.

In the Appendix, the effect of a change in the limit on emissions L on product price, output, emissions per firm and the number of firms is derived. With this, we can also analyze the effect of the introduction of regulation, where we assume that L changes from not binding to just being binding. As is shown in the Appendix, for both permit and credit trading we find $dq/dL > 0$, $dE/dL > 0$ and $dp/dL \leq 0$. The introduction of emissions trading will result in a decrease in production per firm, a decrease in emissions per firm and an increase in the price of the product. The latter also implies that total output will be lower. For both schemes, it remains uncertain whether the number of firms increases or decreases as a result of regulation. The outcome depends on the cost function and on the slope of the demand function. The steeper the demand curve, the more likely it is that the number of firms will increase as the limit on total emissions is set lower. When the demand curve is rather flat, one would expect a reduction in the number of firms. Hence, under both emissions trading schemes regulation could result in an increase or a decrease in the number of firms in the market.

It is possible to compare the equilibria under the two schemes. For all firms in a permit and credit trading scheme it must hold that marginal cost is equal to average cost:

$$C_{q^p}(q^p, E^p) = \frac{C(q^p, E^p) + R^p E^p}{q^p}$$

$$C_{q^c}(q^c, E^c) - R^c \bar{e}^c = \frac{C(q^c, E^c) + R^c(E^c - \bar{e}^c q^c)}{q^c}$$

Here, the superscripts p and c denote permit and credit trading respectively. Rewriting the above conditions, using the long-run optimality conditions, we find that under both schemes optimal production is determined by

$$C(q, E) = qC_q - RE \tag{5}$$

Hence, if $R^c = R^p$, output and emissions per firm are identical under the two schemes. However, we know that $R^c > R^p$. Higher R leads to lower emissions and lower production, therefore $E^p > E^c$ and $q^p > q^c$. Furthermore, from $p^p > p^c$ and $q^p > q^c$ it follows that $n^p < n^c$. So I find that production and emissions per firm are higher and the number of firms is lower under permit trading than under credit trading.

2.2 Imperfect Competition

With imperfect competition, each firm has an influence on the market price of the product. We will assume Cournot competition between the competitor so that $p = p(Q)$, i.e., price is a function of total output. Furthermore, firms will have an influence on the relative standard set with credit trading through the level of output. This implies that $\bar{e} = \bar{e}(Q)$.

Short run. We assume here that in the short run governments do not have time to adjust the standard. This will not be of relevance in a permit trading system, but it will be in a credit trading scheme, since here fluctuations in output affect total emissions.

With imperfect competition and permit trading, the profit function for a firm becomes

$$\pi = p(Q)q - C(q, E) - R^p(E - \bar{E})$$

The first order conditions for profit maximization are

$$\frac{\partial \pi}{\partial q} = p'q + p - C_q = 0$$

$$\frac{\partial \pi}{\partial E} = -C_E - R^p = 0$$

So, the firm should equate marginal revenue with marginal production costs and marginal costs of abatement with the price of permits.

As mentioned above, we assume that in the short run the government cannot change the standard. This implies that in the short run $\bar{e}$ is a constant and is not influenced by the output decisions of any firm. When regulation takes the form of credit trading, the profit function becomes

$$\pi = p(Q)q - C(q, E) - R^c(E - \bar{e}q)$$

The first order conditions for profit maximization are

$$\frac{\partial \pi}{\partial q} = p'q + p - C_q + R^c\bar{e} = 0 \tag{6}$$

$$\frac{\partial \pi}{\partial E} = -C_E - R^c = 0$$

It is clear that the short-run first order conditions for imperfect competition closely resemble those for perfect competition. The only difference is that under imperfect competition firms take the effect of changes in their own output on the price of the product into account. This results in lower aggregate output and higher product prices. Also with imperfect competition output will be higher and the product price lower with credit trading than with permit trading.

Long Run In the long run, the government will be able to change the standard set. Specifically, the government will ensure that $nE = L$. Different from perfect competition, even in the long run, oligopolistic firms can make a profit. However, also with imperfect competition, the number of firms can vary through entry and exit. More precisely, the equilibrium number of firms will be such that if one firm entered the market all firms would make a loss. That is, n^* is the equilibrium number of firms for which it holds that

$$\pi_i(n^*) \geq 0, \quad \text{and} \quad \pi_i(n^* + 1) < 0 \tag{7}$$

Note that we can state these conditions in this way because we have assumed that firms are identical.

With permit trading, the optimality conditions for the long run are then identical to those for the short run plus (7). However, with credit trading, the firm now knows that its actions will have an influence on the standard set. Recall from above that the standard is $\bar{e} = \frac{L}{Q}$ Hence, the profit function with credit trading becomes

$$\pi = P(Q)q - C(q, E) - R^c(E - \frac{L}{Q}q)$$

The first order conditions for profit maximization are

$$P'q + P = C_q - R^c\left(\frac{L}{Q} - q\frac{L}{Q^2}\right) \tag{8}$$

$$-C_E = R^c$$

From a comparison of (8) with (6), it is clear that production will be less in the long run than in the short run. In the long-run, the firm knows that a change in output will have an influence on the relative standard set. So with monopoly $Q = q$, and (8) becomes $P'q + P = C_q$. That means that a monopolist is perfectly aware that as it changes its output, the change in the standard will be equivalent. Hence, in this case, there is no difference between a credit and a permit trading scheme, or for that matter, regulation through an absolute or relative standard. In general then, the lower the number of firms in the market, the more closely the outcomes under credit and permit trading resemble each other.

With imperfect competition, it is not possible to determine exactly what the effects of regulation are on the industry, except that emissions will decrease. The largest problem is that we cannot determine the number of firms in the regulated sector. Especially with imperfect competition, the number of firms in the market is important because it determines the degree of market power of the firms. The lower the number of firms, the larger their market power and the higher the price of the product. However, one would expect the same relationship as under perfect competition. So it is likely that the number of firms and total output is larger under credit trading than under permit trading.

2.3 Welfare

The emission trading schemes described above will have a different impact on welfare. Here, welfare is given by the consumer surplus plus industry profits. To compare the performance of the two instruments, we assume that they are set such as to give the same amount of total emissions L. The problem now is to maximize

$$W = \int_0^{nq} P(Y)dY - nC(q, E) - \lambda(nE - L) \tag{9}$$

Here Y is total demand. In the short run, only the production function is variable, while the number of firms, n, and the total ceiling on emissions, L, are fixed. The latter two imply that E and λ are fixed. Maximizing (9) with respect to q gives as the short run first order condition

$$P = C_q$$

In the long-run, all variables can change. Therefore, to find the optimum, we must maximize (9) with respect to q, n, E, and λ, which gives

$$\begin{aligned} P &= C_q \\ Pq &= C(q,E) - \lambda E \\ -C_E &= \lambda \\ nE &= L \end{aligned}$$

A comparison of the conditions for optimal welfare with the optimality conditions for firms shows that optimal welfare will only be realized when the industry is perfectly competitive and regulated through permit trading. With perfect competition, credit trading always leads to lower levels of welfare. The reason for this is that credit trading is an inefficient instrument because it limits the options for reducing emissions. One effective way to reduce emissions is by reducing output. However, under credit trading, this option will not be utilized to its maximum because reducing output also reduces the total allowable amount of emissions for the firm.

With imperfect competition it is not immediately clear which instrument leads to highest welfare. Permit trading will lead to the most efficient regulation with lowest compliance costs. However, credit trading leads to higher output, which is welfare improving since imperfect competition always leads to lower than optimal output. If credit trading leads to much higher output at not too higher costs than permit trading it will lead to higher welfare than permits trading. However, the reverse is possible too. Furthermore, the number of firms will have an influence on the outcome. As we saw above, the lower the number of firms, the more the outcome under credit trading resembles that under permits trading. On the other hand, with many firms, we approach perfect competition where the difference will be more pronounced. Hence, the more firms in the market the larger the difference in output will be between the two instruments.

2.4 Combining Permit and Credit Trading

It is very well possible that permit and credit trading will be combined, both at the national and at the international level. The UK greenhouse gas emissions trading scheme already combines both systems (DETR (2001)). Here, some sectors were initially regulated through relative standards, while others were not regulated. The latter could voluntarily join a permit trading scheme, while the former are allowed to trade credits under some restrictions. Also in the proposed Dutch trading scheme, permit and credit trading are combined (CO2 Trading Commission (2002)). The European Commission has chosen for a cap and trade system, so that a combination of permit and credit trading should not be possible within the EU. However, if non-EU countries start credit trading schemes and connect it with the EU scheme, combined trading will still be possible.

Combining the two systems has several implications for the emissions and output levels in the two sectors. Assume two identical perfectly competitive industries, facing identical demand functions, where one is regulated through credit trading and the other through permit trading. It then follows from the analysis above that product price will be lower and the emissions quota will be higher in the credit sector than in the permit sector. Combining the two sectors leads to an equalization of the emission quota price between the two sectors and permits will flow from the permit to the credit sector. From (5) it follows that firm production will be equal under the two schemes in equilibrium. From (2) and (4), it also follows that emissions per firm will be equal under the two schemes. Since the permit sector now faces higher marginal abatement costs, production in this sector will decrease and product price will increase. The reverse holds for the credit sector. This implies that if the two sectors are operating on the same market, the permit sector will be competed out of the market because of the lower marginal production costs of the credit sector. If the sectors produce different, unrelated products, the result will be less pronounced, but it is clear that combining the two schemes will also lead to inefficient distortions in that case. With imperfect competition, the effects of combining permit and credit trading are basically the same as with perfect competition, although less pronounced. This is because in many cases a large change in profits is needed to change the number of competitors in the sector.

This has some implications for the optimal choice of instrument when there is international competition. If foreign competition is not regulated, any domestic regulation will lead to the domestic sector disappearing if there is perfect competition. If foreign competition is regulated, it becomes important which type of regulation is chosen. Credit trading leads to lower marginal production costs, so when foreign competition is regulated through this instrument and there is perfect competition, domestic regulation must be credit trading too or else the domestic industry will vanish. Only when foreign competition is regulated through permit trading does the domestic regulator have a real choice between permit and credit trading. When there is imperfect competition, the impact on the domestic sector will not be as far reaching as with perfect competition. It will however still be the case that the sector will suffer if it is regulated while foreign competition is not, or when foreign competition is regulated through credit trading while domestic industry is regulated through permit trading.

In the short run, it is possible that credit trading sector emissions are higher than the emission limit for the sector. This effect may be more pronounced when the two schemes are combined. As seen above, combining permit and credit trading leads to higher production in the credit trading sector. In the short run, with the relative standard $\bar{e}$ fixed, this leads to higher allowed emissions, since this is defined as production times the relative standard.

If the sectors are not similar, another implication of combining the two schemes can be that emissions in the permit sector will be higher than the limit. This could happen if marginal abatement costs are lower in the credit sector than in the permit sector. Then credits would flow to the permit sector. This would not affect total emissions from the two sectors. However, if production is increased in the credit sector, total allowable emissions will increase and total emissions will be higher than the total absolute limit. However, these problems with combining permit and credit trading will only arise if the relative standard underlying the credit system is not adjusted as a response to the problems. Hence, there is only a problem in the short run. It has to be acknowledged though that the short run can take quite some time.

3 Simulation

Although the analysis above answers many questions, some are still left open. The effect on the number of firms is still not fully clear and the size of the effects discussed above are unknown. Furthermore, the outcome under imperfect competition is not entirely clear. The general model cannot be solved for a long-run equilibrium and hence, many questions were left unanswered. To analyze these problems, we will deploy a more specific model. Numerical simulations will then be used to analyze several scenarios.

The specific cost function used in the remainder of the paper is given by

$$C(q, E) = aq^2 + b(q - E)^2 + K$$

Here, a and b are parameters and K gives fixed costs. It can easily be verified that this cost function satisfies all first and second order conditions stated above for the general function. Furthermore, the inverse demand function is linear and is given by

$$p(nq) = \alpha - \beta nq$$

3.1 Perfect Competition

No Regulation. The situation without regulation is the starting point of the analysis and gives a benchmark for the changes caused by regulation. Without regulation, profits for a firm are given by

$$\pi = pq - aq^2 - b(q - E)^2 - K$$

The first order conditions for profit maximization are

$$\frac{\partial \pi}{\partial q} = p - 2aq - 2b(q - E) = 0 \tag{10}$$

$$\frac{\partial \pi}{\partial E} = 2b(q - E) = 0 \quad \Rightarrow \quad q = E \tag{11}$$

Besides these conditions, in the long run it must hold that $C_q = \frac{C}{q}$, i.e., there should be no profits:

$$2aq + 2b(q - E) = \frac{aq^2 + b(q - E)^2 + K}{q}$$

Using (11) we find

$$q = \sqrt{\frac{K}{a}}$$

To find the market price of the good, insert this into (10) to find:

$$p = 2a\sqrt{\frac{K}{a}}$$

The total number of firms is found by inserting the market price in the inverse demand function and solving for n. This gives

$$n = \frac{\alpha\sqrt{\frac{a}{K}} - 2a}{\beta}$$

The three equations for q, p and n fully determine the equilibrium in the no regulation case. Denote the equilibrium values of firm output, product price and number of firms in the no-regulation case by q^0, p^0 and n^0 respectively

Permit Trading. With permit trading, the government distributes a number of permits to each incumbent firm equal to

$$\bar{E} = \frac{L}{n^0}$$

The problem for the firm is to

$$\max_{q,E} \quad \pi = pq - aq^2 - b(q-E)^2 - K - R^p(E - \bar{E})$$

The first order conditions are given by

$$\frac{\partial \pi}{\partial q} = p - 2aq - 2b(q-E) = 0$$

$$\frac{\partial \pi}{\partial E} = 2b(q-E) - R^p = 0$$

Two further condition that need to hold in equilibrium are

$$nE = L$$

$$2aq + 2b(q-E) = \frac{aq^2 + b(q-E)^2 + K + R^p\, E}{q}$$

The first condition says that total emissions should be equal to total allowable emissions, while the second condition is the long-run zero-profit condition.

The equilibrium number of firms n^* can be inferred from

$$\frac{b\,L\,n + \sqrt{K\,n^4 (a+b) - a\,b\,L^2\,n^2}}{n^2\,(a+b)} = \frac{2\,b\,L + n\,\alpha}{n\,(2\,a + 2\,b + n\,\beta)}$$

Using n^*, the system can be solved for the other variables.

Credit Trading Under regulation with credit trading, the government sets a relative standard equal to

$$\bar{e} = \frac{L}{nq}$$

Firms are then allowed to sell credits if they can stay below their total allowed emission level given by $\bar{e}q$. With credit trading, the problem for the firm is

$$\max_{q,E} \quad \pi = pq - aq^2 - b(q-E)^2 - K - R^c(E - \bar{e}q)$$

The first order conditions are

$$\frac{\partial \pi}{\partial q} = p - 2aq - 2b(q-E) + R^c\bar{e} = 0 \tag{12}$$

$$\frac{\partial \pi}{\partial E} = 2b(q-E) - R^c = 0 \tag{13}$$

Other conditions that need to hold are

$$nE = L$$

$$2aq + 2b(q - E) - R^c \bar{e} = \frac{aq^2 + b(q-E)^2 + K + R^c(E - \bar{e}q)}{q}$$

Which state that total emissions should equal total allowed emissions and that profits should be zero. In equilibrium, $E = L/n$, and no emissions trading will take place since all firms are identical and the relative standards are set anew in every period.

The equilibrium number of firms n^* can be inferred from

$$\frac{4\,b\,L\,n + n^2\,\alpha + \sqrt{n^2\,\left(n\,\left(n\,\alpha^2 - 8\,b\,L\,\left(-\alpha + L\,\beta\right)\right) - 16\,a\,b\,L^2\right)}}{2\,n^2\,\left(2\,a + 2\,b + n\,\beta\right)}$$
$$= \frac{b\,L\,n + \sqrt{a\,K\,n^4(a+b) - a\,b\,L^2\,n^2}}{(a+b)\;n^2}$$

As before, the system can be solved using n^*

Combined Trading The model can also be used to analyze the effects of combining permit and credit trading. With perfect competition, the only interesting case is the one where two sectors operating on different product markets are connected through emissions trading. If two sectors, from different countries for example, operating on the same product market would be connected through emissions trading, the sector regulated through permit trading would vanish because of its higher marginal production costs.

In the following, we assume that the two sectors are identical in all aspects, except that they operate on two different product markets, which have identical demand functions, and that one sector is regulated through permit trading, while the other is regulated through credit trading. Under these specifications, the emissions quota price will be higher in the credit sector than in the permit sector, prior to combining the sectors. Therefore, emission quotas will flow from the permit to the credit sector. In the case of combined trading, an additional condition is needed, given by

$$n^c E^c + n^p E^p = 2L \tag{14}$$

This condition merely says that total emissions should be equal to total allowable emissions. Furthermore, it must now hold that $R^p = R^c = R$.

Firm production in the permit and credit sectors is equal (see Section 2.1) and becomes

$$q^p = q^c = \frac{\sqrt{4\,b\,K - R^2}}{2\,\sqrt{a}\,\sqrt{b}}$$

The number of firms in the permit sector is given by

$$n^p = \frac{4\,a\,\beta\,(R^2 - 4\,b\,K) - \beta\,(R-\alpha)\,\sqrt{4ab\,(4\,b\,K - R^2)}}{2\beta^2\,\left(4\,b\,K - R^2\right)}$$

and firm emissions in the permit sector are

$$E^p = \frac{\sqrt{b\,(4\,b\,K - R^2)} - R\sqrt{a}}{2b\,\sqrt{a}}$$

For the credit sector we find the following for the number of firms and firm emissions:

$$\begin{aligned} n^c = & \frac{1}{\delta\beta}\Big\{-a\,(\delta) - (R-\alpha)\,\sqrt{ab\delta} + \sqrt{a\delta} \\ & * \sqrt{\left(a\delta + (R-\alpha)\,\sqrt{4ab\delta} + b\,((R-\alpha)^2 + 4LR\beta)\right)}\Big\} \end{aligned}$$

$$E^c = \frac{\sqrt{b\delta} - R\sqrt{a}}{2b\sqrt{a}}$$

where

$$\delta = 4bK - R^2$$

The equations for n^p, n^c, E^p, E^c are all functions of R. Inserting these equations in the emissions constraint (14) gives an equation with only R unknown. This can then be solved and used to solve for the other unknowns.

Simulation Results The simulation results for perfect competition are shown in Tables 1-3. All three examples are constructed such that without regulation output per firm is 1, the number of firms is 100 and product price is 2. It is assumed that the aim of the government is to reduce emissions with 30% relative to no regulation, which leads to an overall limit of emissions of 70. The difference between the three cases lies in the demand function. In Table 1, the slope of the demand function is relatively steep and demand is inelastic at the equilibrium price. In Table 2 the slope of the demand function is steeper, and even more so in Table 3 where demand is elastic at the equilibrium price.

The simulation results confirm the results of the general analysis given in Section 2.1. Regulation leads to lower output and higher product prices. Furthermore, the simulations show that production per firm is higher under permit than under credit trading, but that total production, the number of firms and the emissions quota price is higher under credit trading.

Table 1: Perfect Competition: Inelastic Demand 1

$a = 1,\ K = 1,\ \alpha = 102,\ \beta = 1$

$q^0 = 1,\ n^0 = 100,\ E^0 = 1,\ p^0 = 2,\ L = 70$

	Permit Trading					Credit Trading				
b	q^p	n^p	E^p	P^p	R^p	q^c	n^c	E^c	P^c	R^c
1	0.96	103.8	0.67	2.49	0.57	0.96	104.3	0.67	2.09	0.57
2	0.92	107.3	0.65	2.93	1.08	0.92	108.3	0.65	2.17	1.10
3	0.89	110.4	0.63	3.34	1.56	0.89	112,3	0.62	2.25	1.59
4	0.87	113.4	0.62	3.73	1.99	0.86	116,0	0.60	2.33	2.05
5	0.84	116.1	0.60	4.09	2.40	0.83	119.6	0.59	2.40	2.48
6	0.82	118.7	0.59	4.43	2.79	0.81	123.0	0.57	2.47	2.88
7	0.80	121.0	0.58	4.76	3.15	0.79	126.4	0.55	2.54	3.26
8	0.79	123.3	0.57	5.07	3.50	0.77	129.6	0.54	2.61	3.63
9	0.77	125.4	0.56	5.36	3.82	0.75	132.7	0.53	2.67	3.98
10	0.76	127.4	0.55	5.65	4.14	0.73	135.7	0.52	2.73	4.31

Combined Trading									
	Permit Sector					Credit Sector			
b	q^p	n^p	E^p	p^p	R	q^c	n^c	E^c	P^c
1	0.96	103.8	0.67	2.49	0.57	0.96	104.3	0.67	2.09
2	0.92	107.4	0.65	2.94	1.09	0.92	108.2	0.65	2.17
3	0.89	110.7	0.63	3.35	1.57	0.89	112.0	0.63	2.25
4	0.86	113.8	0.61	3.75	2.02	0.86	115.5	0.61	2.33
5	0.84	116.8	0.59	4.12	2.44	0.84	118.8	0.59	2.40
6	0.82	119.6	0.58	4.47	2.83	0.82	122.0	0.58	2.47
7	0.80	122.2	0.57	4.80	3.21	0.80	125.0	0.57	2.54
8	0.77	124.7	0.55	5.12	3.56	0.78	128.0	0.55	2.61
9	0.76	127.1	0.54	5.42	3.90	0.76	130.8	0.54	2.67
10	0.74	129.4	0.53	5.71	4.23	0.74	133.4	0.53	2.73

Table 2: Perfect Competition: Inelastic Demand 2

$a = 1$, $K = 1$, $\alpha = 12$, $\beta = 0.1$

$q^0 = 1$, $n^0 = 100$, $E^0 = 1$, $p^0 = 2$, $L = 70$

	Permit Trading					Credit Trading				
b	q^p	n^p	E^p	P^p	R^p	q^c	n^c	E^c	P^c	R^c
1	0.97	98.9	0.71	2.45	0.52	0.96	103.4	0.68	2.08	0.56
2	0.95	97.1	0.72	2.80	0.91	0.93	106.3	0.66	2.16	1.07
3	0.94	95.2	0.74	3.08	1.21	0.90	108.9	0.64	2.23	1.53
4	0.93	93.2	0.75	3.31	1.45	0.87	111.2	0.63	2.29	1.95
5	0.93	91.4	0.77	3.50	1.64	0.85	113.3	0.62	2.35	2.34
6	0.93	89.7	0.78	3.66	1.80	0.83	115.2	0.61	2.40	2.71
7	0.93	88.2	0.79	3.79	1.92	0.82	117.0	0.60	2.45	3.05
8	0.93	86.8	0.81	3.90	2.03	0.80	118.6	0.59	2.49	3.38
9	0.94	85.6	0.82	3.99	2.12	0.79	120.1	0.58	2.54	3.69
10	0.94	84.5	0.83	4.07	2.20	0.78	121.4	0.58	2.58	3.99

Combined Trading

	Permit Sector					Credit Sector			
b	q^p	n^p	E^p	p^p	R	q^c	n^c	E^c	P^c
1	0.96	99.0	0.69	2.47	0.54	0.96	103.0	0.69	2.08
2	0.94	97.5	0.69	2.86	0.98	0.94	105.0	0.69	2.16
3	0.92	95.7	0.69	3.20	1.36	0.92	106.3	0.69	2.23
4	0.91	93.7	0.70	3.50	1.68	0.91	107.1	0.70	2.28
5	0.90	91.7	0.70	3.76	1.96	0.90	107.5	0.70	2.34
6	0.89	89.7	0.71	3.99	2.20	0.89	107.6	0.71	2.39
7	0.89	87.7	0.72	4.20	2.42	0.89	107.6	0.72	2.43
8	0.89	85.8	0.72	4.38	2.61	0.89	107.4	0.72	2.47
9	0.89	84.0	0.73	4.55	2.77	0.89	107.1	0.73	2.50
10	0.89	82.4	0.74	4.70	2.92	0.89	106.8	0.74	2.54

Table 3: Perfect Competition: Elastic Demand 2

$a = 1$, $K = 1$, $\alpha = 3$, $\beta = 0.01$

$q^0 = 1$, $n^0 = 100$, $E^0 = 1$, $p^0 = 2$, $L = 70$

	Permit Trading					Credit Trading				
b	q^p	n^p	E^p	P^p	R^p	q^c	n^c	E^c	P^c	R^c
1	0.99	79.4	0.88	2.21	0.22	0.97	96.7	0.72	2.06	0.49
2	1.00	75.2	0.93	2.25	0.26	0.95	94.6	0.74	2.10	0.85
3	1.00	73.6	0.95	2.27	0.27	0.94	93.2	0.75	2.12	1.15
4	1.00	72.7	0.96	2.27	0.28	0.94	92.2	0.76	2.14	1.41
5	1.00	72.2	0.97	2.28	0.28	0.93	91.4	0.77	2.15	1.64
6	1.00	71.8	0.97	2.28	0.29	0.93	90.7	0.77	2.16	1.85
7	1.00	71.6	0.98	2.29	0.29	0.92	90.2	0.78	2.17	2.04
8	1.00	71.4	0.98	2.29	0.29	0.92	89.7	0.78	2.18	2.22
9	1.00	71.2	0.98	2.29	0.29	0.92	89.3	0.78	2.18	2.39
10	1.00	71.1	0.98	2.29	0.29	0.91	88.9	0.79	2.19	2.56

Combined Trading

	Permit Sector					Credit Sector			
b	q^p	n^p	E^p	p^p	R	q^c	n^c	E^c	P^c
1	0.99	72.4	0.83	2.28	0.31	0.99	95.6	0.83	2.06
2	0.99	63.5	0.89	2.37	0.39	0.99	93.3	0.89	2.08
3	0.99	59.6	0.92	2.41	0.42	0.99	92.2	0.92	2.08
4	0.99	57.6	0.94	2.43	0.44	0.99	91.6	0.94	2.09
5	0.99	56.3	0.95	2.44	0.45	0.99	91.2	0.95	2.09
6	1.00	55.4	0.96	2.45	0.46	1.00	90.9	0.96	2.09
7	1.00	54.7	0.96	2.46	0.46	1.00	90.7	0.96	2.10
8	1.00	54.3	0.97	2.46	0.47	1.00	90.5	0.97	2.10
9	1.00	53.9	0.97	2.46	0.47	1.00	90.4	0.97	2.10
10	1.00	53.5	0.97	2.47	0.47	1.00	90.3	0.97	2.10

The simulations show that regulation can lead to a decrease, but also an increase in the number of firms in the sector. As a review of Tables 1-3 shows, the number of firms in the market depends on the slope of the demand function and the elasticity of demand. In the case given in Table 1, the slope of the demand function is -1 and the elasticity of demand under no regulation is -0.02. Under both permit and credit trading, the number of firms increases as compared to no regulation, although more with credit trading than with permit trading. However, as the slope of the demand function becomes less steep and demand more elastic, the number of firms in both sectors increases as is clear from Tables 2 and 3 where the elasticity is -0.2 and -2 respectively under no regulation. The explanation for this is rather simple. Regulation increases the costs of production and thereby the price of the product. If demand is inelastic, total output will not change much, while output will decrease by a large amount if demand is elastic. At the same time, regulation changes the optimal production level for the firm so that output per firm becomes lower and more so with credit trading than with permit trading. When demand is inelastic, total output does not change much when regulation increases the price of the product. However, optimal firm output decreases, so that more firms can exist in the market. When demand is more elastic, total output decreases more and fewer firms can survive in the market. At some point, demand decreases by so much with a one percent increase in price that the total number of firms decreases compared with no regulation.

It is interesting to see that in general the outcome is dependent on the elasticity of demand. For example, the higher the elasticity of demand, the lower the emissions quota price, and the larger the difference between the permit and credit price. With high elasticity, an increase in price gives a relative large decrease in output and thereby also in emissions. Hence, the price on emissions does not need to be very high to achieve a certain reduction in emissions. But credit trading gives a smaller decrease in emissions for a given emissions quota price because of the implicit output subsidy that is inherent in this system. The effect of the output subsidy will be larger, the larger the elasticity is. Hence, the credit price must be higher than the permit price and must be relatively higher when demand is more elastic.

Combining permit and credit trading leads to an emission quota price that lies in between the permit and credit price. Hence, permits will flow from the permit sector to the credit sector. The result is an increase in production, both per firm and in total, in the credit sector and a decrease in production in the permit sector. So combining the two schemes leads to even larger inefficiencies in that credit sector production is increased above the already too high level.

3.2 Imperfect Competition

With imperfect competition, firms have market power in the product market. Furthermore, as we have seen above in the theoretical analysis, individual firms have an influence on the relative standard set with credit trading.

No Regulation The no regulation case is used as a starting point for the analysis and as a benchmark to measure changes against. Assuming that all firms are identical and keeping the same general cost function as the one given above, profits are given by

$$\pi_i = P(Q)q_i - aq_i^2 - b(q_i - E_i)^2 - K$$

where $Q = \sum_{i=1}^{n} q_i$. Using the demand function, the first order conditions are found to be

$$\frac{\partial \pi_i}{\partial q_i} = \alpha - \beta q(n+1) - 2aq_i - 2b(q_i - E_i) = 0$$

$$\frac{\partial \pi_i}{\partial E_i} = 2b(q_i - E_i) = 0 \quad \Rightarrow \quad q_i = E_i$$

With imperfect competition, firms can earn a profit, even in the long-run. However, the number of firms need not be constant over time. The long-run equilibrium conditions with imperfect competition are that all firms in the market should at least cover their costs, i.e., $\pi_i \geq 0$ and that entry should not be profitable. These conditions can be given as

$$\pi_i(n^0) \geq 0, \quad \text{and} \quad \pi_i(n^0 + 1) < 0$$

Where n^0 is the equilibrium number of firms in the market without regulation. The equilibrium output level per firm is then given by

$$q_i = \frac{\alpha}{2a + (1 + n^0)\beta}$$

Permit Trading With permit trading, the government puts a limit L on total emissions, giving an initial distribution of permits per firm of $\bar{E} = L/n^0$. The profit function for the firm then becomes:

$$\pi = p(Q)q_i - aq_i^2 - b(q_i - E_i)^2 - K - R^p(E_i - \bar{E})$$

The first order conditions for profit maximization are

$$\frac{\partial \pi}{\partial q_i} = \alpha - \beta q_i(n+1) - 2aq_i - 2b(q_i - E_i) = 0 \tag{15}$$

$$\frac{\partial \pi}{\partial E_i} = 2b(q_i - E_i) - R^p = 0$$

Since we have assumed that firms are identical, emissions after trading will be $E_i = L/n$.

Equilibrium output per firm is given by

$$q = \frac{2\,b\,L + n\,\alpha}{n\,\left(2\,a + 2\,b + \beta + n\,\beta\right)}$$

The equilibrium number of firms can be inferred from

$$2K = \frac{2bL^2}{n^2} + \frac{\lambda\beta}{n^2\nu^2} + \frac{\mu - \lambda\beta}{n\nu^2} + \frac{\alpha^2\beta(1-n) - \mu}{\nu^2} - \frac{\lambda}{n^2\nu} + \frac{\alpha^2}{\nu} \tag{16}$$

where

$$\lambda = 4b^2L^2, \quad \mu = 4bL\alpha\beta, \quad \text{and} \quad \nu = 2a + 2b + \beta + n\beta$$

The equilibrium number of firms is found by solving (16) for n and rounding down to the nearest integer.

Credit Trading With credit trading, the profits of a firm become

$$\pi_i = p(Q)q_i - aq_i^2 - b(q_i - E_i)^2 - K - R^c E_i - \bar{e}q_i)$$

where $\bar{e} = L/Q_{t-1}$. The first order conditions for profit maximization are

$$\frac{\partial \pi_i}{q_i} = \alpha - \beta q_i(n+1) - 2aq_i - 2b(q_i - E_i) + R^c\bar{e} = 0$$

$$\frac{\partial \pi_i}{\partial E_i} = 2b(q_i - E_i) - R^c = 0$$

$$q = \frac{2bLn\,(2n-1) + n^3\alpha + \phi}{2n^3\nu}$$

where

$$\phi = \sqrt{\left(-2bLn + 4bLn^2 + n^3\alpha\right)^2 - 8bL^2\left(-1+n\right)n^3\left(\nu\right)}$$

The number of firms can be inferred from

$$4K = +\frac{\alpha^2}{\nu} - \frac{4bL^2}{n^3} + \frac{\alpha\beta(\alpha - n\alpha - 8bL)}{\nu^2} - \frac{4b^2L^2}{n^4\nu} - \frac{8bL^2\beta}{n^2\nu} + \frac{2bL\phi}{n^5\nu}$$
$$-\frac{2bL\beta\phi}{n^5\nu^2} + \frac{2bL\beta(2bL + 3\phi)}{n^4\nu^2} + \frac{32b^2L^2\beta - 4bL\alpha\beta - \alpha\beta\phi}{n^2\nu^2} + \frac{4bL\beta(3\alpha - 4bL)}{n\nu^2}$$
$$+\frac{4bL(L\beta + \alpha)}{n\nu} + \frac{\alpha\beta\phi - 20b^2L^2\beta - 4bL\beta\phi}{n^3\nu^2} + \frac{\alpha\phi + 8b^2L^2 + 4bL^2\beta}{n^3\nu}$$

Combined Trading As with perfect competition, we can combine the two systems. Additionally, saying that total real emissions are equal to total allowed emissions

$$2L = n^c E^c + n^p E^p \tag{17}$$

Furthermore, the permit and credit price will now be equal

$$R^p = R^c = R$$

For permit trading we can derive the following equations for output per firm and the number of firms in the permit sector

$$q^p = \frac{-R+\alpha}{2\,a+\beta+n^p\,\beta}$$

To find the number of firms in the permit sector, long-run profits are set equal to zero to find

$$\begin{aligned} 4bK - R^2 + \frac{2b\beta(nR^2+2R\alpha+n^p\alpha^2)}{\eta^2} + \frac{4bR\alpha}{\eta} \\ = \frac{2b\beta\,(R^2+2n^pR\alpha+\alpha^2)}{\eta^2} + \frac{2b(R^2+\alpha^2)}{\eta} \end{aligned}$$

where

$$\eta = 2a+\beta+n\beta$$

This can be solved numerically. The equilibrium number of firms for every emission quota price R is found by rounding the value for n^p down to the nearest integer.

For output per firm and the number of firms in the credit sector, we find

$$q^c = \frac{n^{c2}\,(\alpha - R)+\sigma}{2n^{c2}\rho}$$

where

$$\rho = 2a+\beta+n^c\beta, \quad \sigma = \sqrt{n^{c4}(R-\alpha)^2 + 4L\,(-1+n^c)\,n^{c2}R\,(\rho)}$$

The number of firms in the credit sector can be derived from

$$\begin{aligned} 4bK - R^2 + \frac{b\beta(n^cR^2+2R\alpha+n^c\alpha^2)}{\rho^2} + \frac{2bR(\alpha+L\beta)}{\rho} \\ + \frac{bR(\sigma+2L\beta)-b\alpha\sigma}{n^{c2}\rho} + \frac{b\beta\sigma(R-\alpha)}{n^{c2}\rho^2} - \frac{2bLR}{n^{c2}} - \frac{2bLR}{n^c} \\ = \frac{b\beta(R^2+2n^cR\alpha+\alpha^2)}{\rho^2} + \frac{b(R^2+\alpha^2)}{\rho} + \frac{4bLR\beta}{n^c\rho} + \frac{b\beta\sigma(R-\alpha)}{n^c\rho^2} \end{aligned}$$

Using these equations and the first order condition for emissions, we can derive equations for n^p, E^p, n^c, and E^c that are only functions of R. However, because the number of firms in each sector is an integer, and the expressions above give a rational number, we cannot derive an expression for the equilibrium value of R. The equilibrium value of R was found through iteration, where the starting value of the iteration was R^p for every case and a small amount was added until the equilibrium value was found.

Simulation Results The simulation results for imperfect competition are shown in Tables 4-7, with market performance given in the first two tables and welfare in the last two. In both cases, there are four firms when there is no regulation. However, because the demand functions are different, production and emissions are different in the two cases. In both cases, demand is inelastic when there is no regulation.

The immediate result that follows from the two cases is that the outcome depends to a large degree on the number of firms in the industry after regulation. With permit trading, there is a tendency that there will be fewer firms, while with credit trading, the number of firms may increase as a result of regulation. This is the same as what we found under perfect competition. However, whereas with perfect competition, the number of firms was just a result, not affecting the outcome, under imperfect competition, the number of firms in the market has an impact on the outcome. A decrease in the number of firms gives the remaining firms more market power, which in turn leads to lower industry output, higher prices and higher profits.

Look first at permit trading. As long as the number of firms does not change with regulation, as is the case for all but the highest value of b in Table 5, the result is as one would expect. Production per firm, and thereby total production decreases, the price of the product increases and profits fall as a result of regulation. The higher b, which can be taken as a measure of marginal abatement costs, the more pronounced the effects are. However, when the number of firms decreases (see Table 4), production and emissions per firm increase, although the price of the product always increases. Furthermore, profits may now also increase as a result from regulation. So in this case, regulation may even be beneficial to the firms, at least to those remaining in the industry. Table 4 even shows that regulation may reduce the number of firms so far that the emission limit is not binding for the remaining firms (for $b = 20$ and $b = 50$).

With credit trading, the effects are somewhat different. If regulation does not alter the number of firms in the market (Table 4) production per firm and total production decrease because of regulation and decrease with increasing b. As a result, product price increases with regulation and with higher b.

Table 4: Imperfect Competition 1

$a = 1$, $K = 100$, $\alpha = 50$, $\beta = 1$

$q_0 = 7.14$, $n_0 = 4$, $E_0 = 7.14$, $p_0 = 21.43$, $\pi_0 = 2.04$ $L = 20$

	Permit Trading						Credit Trading					
b	q_p	n_p	E_p	p_p	π_p	R_p	q_c	n_c	E_c	p_c	π_c	R_c
1	7.92	3	6.67	26.25	26.91	2.50	6.90	4	5.00	22.42	3.44	3.79
2	7.67	3	6.67	27.00	19.56	4.00	6.71	4	5.00	23.15	4.50	6.85
3	7.50	3	6.67	27.50	14.58	5.00	6.57	4	5.00	23.73	5.36	9.40
4	7.38	3	6.67	27.86	11.00	5.71	6.45	4	5.00	24.20	6.09	11.60
5	7.29	3	6.67	28.13	8.29	6.25	6.35	4	5.00	24.59	6.73	13.52
6	7.22	3	6.67	28.33	6.17	6.67	6.27	4	5.00	24.92	7.29	15.23
7	7.17	3	6.67	28.50	4.47	7.00	6.20	4	5.00	25.21	7.80	16.76
8	7.12	3	6.67	28.64	3.08	7.27	6.13	4	5.00	25.46	8.26	18.15
9	7.08	3	6.67	28.75	1.91	7.50	6.08	4	5.00	25.68	8.69	19.43
10	7.05	3	6.67	28.85	0.92	7.69	6.03	4	5.00	25.88	9.08	20.60
20	10.00	2	10.00	30.00	100.00	0.00	5.72	4	5.00	27.11	11.98	28.87
50	10.00	2	10.00	30.00	100.00	0.00	5.40	4	5.00	28.40	16.22	39.95

	Combined Trading										
	Permit Sector						Credit Sector				
b	q_p	n_p	E_p	p_p	π_p	R	q_c	n_c	E_c	P_c	π_c
1	7.80	3	6.21	26.59	24.30	3.18	6.93	4	5.34	22.26	2.67
2	7.43	3	6.08	27.71	14.10	5.42	6.80	4	5.44	22.82	2.81
3	7.15	3	5.98	28.54	6.54	7.08	6.70	4	5.52	23.21	2.74
4	6.94	3	5.89	29.18	0.69	8.36	6.62	4	5.58	23.50	2.59
5	8.33	2	7.49	33.34	42.19	8.36	6.62	4	5.79	23.50	1.72
6	8.33	2	7.63	33.34	41.61	8.36	6.62	4	5.93	23.50	1.13
7	8.33	2	7.73	33.34	41.20	8.36	6.62	4	6.03	23.50	0.72
8	8.32	2	7.80	33.35	40.78	8.38	6.62	4	6.10	23.51	0.41
9	8.25	2	7.77	33.50	38.29	8.74	6.60	4	6.12	23.59	0.26
10	8.19	2	7.74	33.62	36.14	9.06	6.59	4	6.13	23.66	0.12
20	7.04	3	6.85	28.87	0.00	7.73	7.78	3	7.59	26.66	39.01
50	7.06	3	6.98	28.82	0.00	7.64	7.79	3	7.71	26.64	38.54

However, profit actually increases when emissions are regulated and more so with higher b. So, in this case, regulation is beneficial to all incumbent firms. The reason for this is that the product price is pushed upward because of regulation. Since demand is inelastic, revenue will increase. The difference with permit trading, where profits decrease in the same situation, stems from the difference in the long-run costs. With permit trading, firms have to cover the costs of emissions, also those for which they have received permits for free. Under credit trading however, firms only have to cover the expense of credits bought in excess of their initial distribution. Note that when the number of firms is not changed under both permit and credit trading, as shown in Table 5 with $b = 1$, profits are higher under credit trading than under permit trading. This again results from the differences in long-run costs. Under credit trading, the number of firms may increase as a result of regulation. This is shown in Table 5. In that case, firm production still decreases, but now industry production may increase compared to no regulation, as long as abatement costs are not too high. Profits clearly decrease as a result of increased competition in the market.

Combined trading leads to basically the same results with imperfect as with perfect competition. Permits flow from the permit sector to the credit sector, leading to higher production in the credit sector and lower production in the permit sector.

One unresolved question was which instrument would give highest welfare. Here welfare is measured as consumer surplus plus industry profits. As Tables 6 and 7 show, credit trading almost always leads to higher welfare than permit trading. There are two reasons for this. In the first place, credit trading leads, ceteris paribus, to higher output. With imperfect competition, this is in itself a welfare improvement since imperfect competition leads to lower than optimal output. Furthermore, in many cases, the number of firms is larger in the credit sector than in the permit sector, leading to less market power in the credit sector. Only in the cases where the emission limit is no longer binding on the remaining firms in the permit sector will permit trading lead to higher welfare (Table 7, $b = 20$ and $b = 50$). The reason here is not that consumers' surplus is high, but that profits are very high.

The differences between perfect and imperfect competition are clear. Whereas under perfect competition, permit trading always leads to highest welfare, credit trading most often leads to highest welfare under imperfect competition. Furthermore, the outcomes under imperfect competition are much less straightforward, as they depend to a large degree on the number of firms in the market.

Table 5: Imperfect Competition 2

$a = 1$, $K = 100$, $\alpha = 150$, $\beta = 6.6$

$q_0 = 4.29$, $n_0 = 4$, $E_0 = 4.29$, $p_0 = 36.86$, $\pi_0 = 39.59$ $L = 12.00$

	Permit Trading						Credit Trading					
b	q_p	n_p	E_p	p_p	π_p	R_p	q_c	n_c	E_c	p_c	π_c	R_c
1	4.22	4	3.00	38.69	36.58	2.43	4.25	4	3.00	37.75	40.85	2.50
2	4.15	4	3.00	40.34	33.80	4.62	3.55	5	2.40	32.69	0.92	4.62
3	4.10	4	3.00	41.82	31.21	6.59	3.53	5	2.40	33.47	1.87	6.79
4	4.05	4	3.00	43.17	28.83	8.37	3.51	5	2.40	34.20	2.77	8.87
5	4.00	4	3.00	44.40	26.60	10.00	3.49	5	2.40	34.89	3.62	10.88
6	3.96	4	3.00	45.52	24.53	11.49	3.47	5	2.40	35.55	4.42	12.82
7	3.92	4	3.00	46.56	22.59	12.86	3.45	5	2.40	36.18	5.17	14.69
8	3.88	4	3.00	47.51	20.78	14.12	3.43	5	2.40	36.77	5.90	16.50
9	3.85	4	3.00	48.38	19.08	15.28	3.41	5	2.40	37.34	6.58	18.25
10	3.82	4	3.00	49.20	17.49	16.36	3.40	5	2.40	37.89	7.24	19.95
20	3.60	4	3.00	54.96	5.70	24.00	3.26	5	2.40	42.29	12.47	34.55
50	4.28	3	4.00	65.19	43.47	28.35	3.04	5	2.40	49.70	21.36	63.95

	Combined Trading										
	Permit Sector						Credit Sector				
b	q_p	n_p	E_p	p_p	π_p	R	q_c	n_c	E_c	P_c	π_c
1	4.22	4	2.99	38.71	36.57	2.45	4.25	4	3.03	37.73	40.79
2	4.15	4	3.00	40.34	33.80	4.62	3.55	5	2.40	32.69	0.92
3	4.09	4	2.98	41.91	31.15	6.69	3.53	5	2.42	33.43	1.77
4	4.04	4	2.96	43.37	28.64	8.64	3.51	5	2.43	34.11	2.53
5	3.99	4	2.94	44.74	26.28	10.46	3.49	5	2.45	34.74	3.19
6	3.94	4	2.92	46.04	24.03	12.17	3.47	5	2.46	35.33	3.78
7	3.89	4	2.91	47.25	21.90	13.78	3.46	5	2.47	35.87	4.30
8	3.85	4	2.89	48.40	19.88	15.30	3.44	5	2.49	36.38	4.76
9	3.81	4	2.88	49.49	17.95	16.74	3.43	5	2.50	36.85	5.17
10	3.77	4	2.86	50.52	16.12	18.11	3.42	5	2.51	37.30	5.53
20	3.47	4	2.75	58.47	1.62	28.65	3.32	5	2.60	40.58	7.58
50	3.79	3	3.37	74.88	18.32	42.25	3.20	5	2.78	44.41	7.01

Table 6: Welfare with imperfect competition 1

$a = 1$, $K = 100$, $\alpha = 50$, $\beta = 1$				
b	**PT**	**CT**	**CPT**	**CCT**
NR	410.20	410.20	410.20	410.20
1	308.94	383.85	298.28	387.32
2	284.06	364.84	262.58	372.31
3	267.71	350.34	236.86	361.65
4	256.15	338.86	217.40	353.66
5	247.55	329.49	180.89	352.79
6	240.90	321.68	180.31	352.21
7	235.60	315.05	179.89	351.79
8	231.28	309.34	179.36	351.38
9	227.69	304.36	174.45	349.07
10	224.66	299.98	170.23	347.08
20	300.00	273.88	223.33	311.44
50	300.00	249.46	224.35	311.41

Table 7: Welfare with imperfect competition 2

$a = 1$, $K = 100$, $\alpha = 150$, $\beta = 6.6$				
b	**PT**	**CT**	**CPT**	**CCT**
NR	1009.39	1009.39	1009.39	1009.39
1	975.18	995.46	974.93	995.72
2	944.83	1043.38	944.81	1043.39
3	917.73	1030.66	916.33	1031.16
4	893.39	1018.70	890.00	1019.91
5	871.40	1007.42	865.58	1009.55
6	851.45	996.77	842.87	999.95
7	833.26	986.69	821.69	991.05
8	816.62	998.79	801.88	982.75
9	801.33	968.05	783.33	975.02
10	787.24	959.41	765.89	967.77
20	689.98	891.29	636.29	914.63
50	588.41	783.56	445.84	851.60

4 Political Considerations

The analysis above shows under which circumstances which instrument gives highest welfare. Important factors are whether there is perfect or imperfect competition and whether there is foreign competition or not. In general, permit trading is the efficient instrument while credit trading is not. It follows that under perfect competition, permit trading will give highest welfare. However, when there is foreign competition, permit trading may not be very appropriate since it gives higher production costs and may lead to the disappearance of the sector, although this is dependent on the form of regulation abroad. Under imperfect competition, credit trading will in many cases lead to higher welfare than permit trading. The existence of foreign competition would give even more reason to use credit trading.

This is the normative approach; what is best to implement. The other side is the positive approach: which instrument is most likely to be implemented. One factor that influences which instrument is implemented in reality is the preference of interest organizations. Here, I will shortly analyze preferences over permit and credit trading by a few of those organization. For an overview of interest organizations and their preferences for environmental policy instrument, see Boom (2002b).

The largest, but also worst organized group with an interest in which scheme is used are the consumers. Consumers prefer low prices and should therefore clearly prefer credit trading in all cases. Labor unions have a dual goal of high employment and high wage, although the first goal seems to be most important (see Boom (2002b)). This makes that also labor unions will have a preference for credit trading, since this instrument leads to most output, and thereby probably to highest employment. However, labor unions normally do not have much clout in environmental issues. Environmental organizations normally have a considerable influence on environmental policy, but tend to be less interested in instrument choice but more in reaching as low pollution levels as possible. They are however likely to have a preference for the instrument that gives the highest certainty of realizing the abatement goal, which in this case is permit trading.

A group with both a high degree of interest in the choice of instrument and much influence is industry. The basic assumption is normally that the only objective of firms is to maximize profits. With perfect competition, profits are per definition zero under both trading schemes. However, with permit trading, incumbent firms receive permits that can be sold when the firm leaves the industry. Hence, in this case, industry should prefer permit trading. This changes when there is foreign competition. Permit trading leads to the highest production costs, so firms will prefer credit trading, if regulation is unavoidable.

With imperfect competition, the situation becomes harder to assess. As Tables 4 and 5 show, it depends very much on the exact situation which instrument gives highest profits. In general, firms have more market power under permit trading because there tend to be fewer firms than under credit trading. On the other hand, costs are higher under permit trading because here opportunity costs of emissions have to be taken into account. In the two cases shown in Tables 4 and 5, permit trading gives higher profits in more cases than credit trading. If this is any indication for a general trend, then firms should prefer permit trading. If there is foreign competition however, industry will most likely prefer credit trading for the same reasons as those given above under perfect competition.

Politicians have other goals than maximizing national welfare. Mostly, they would like to be reelected. This depends to a high degree on the economic situation of the country. Hence, politicians will prefer low inflation and high employment. Both objectives point to credit trading since this leads to both the lowest increase in price and the lowest decrease in production. If there is foreign competition, the preference for credit trading becomes even more clear.

In all, there is a general preference for credit trading when there is international competition. It has to be kept in mind though that this depends on the choice of instrument in the foreign country. When there is no such competition, industry will have a preference for permit trading. Politicians will prefer credit trading, although permit trading should not be ruled out if the impacts on inflation and employment are minimal.

5 Conclusions

Emissions trading schemes can be build on different foundations and the foundation has a considerable influence on the appearance and functioning of the resulting structure. For emissions trading, the foundation can either be absolute standards, which gives permit trading, the standard emissions trading scheme discussed in the literature. The foundation can also be relative standards, giving credit trading. This paper shows that credit trading is an inefficient form of regulation, leading to too high production levels and too high marginal abatement costs. The reason is that credit trading gives an implicit subsidy on output by allowing more emissions when output is increased. Another general outcome is that the two types of emissions trading have a different impact on industry structure. In general, there will be more firms in an industry regulated through credit trading than in one regulated through permit trading. But under both instruments, the total number of firms can increase or decrease relative to the situation without regulation. This paper also analyzed the effect of combining the two schemes. In that case, permits will flow from the permit to the credit sector, benefiting the credit sector, but increasing the inefficiencies in the system.

In this paper, the working of the two schemes was analyzed under both perfect competition and imperfect competition, and some results are specific for each of these cases. One clear conclusion under perfect competition is that permit trading always leads to higher welfare. This is rather straightforward, since credit trading is an inefficient instruments. Furthermore, under perfect competition, several results are affected by the elasticity of demand. The higher the elasticity of demand, the lower the number of firms in the market. Also other factors, such as the emissions quota price and output per firm are affected by the elasticity of demand.

The main differences with imperfect competition compared to perfect competition are the welfare impacts of the instruments and the fact that the level of profits now becomes important. Under imperfect competition, credit trading will often lead to higher welfare than permit trading. The reason for this is twofold. Firstly, credit trading leads to higher output, thereby adjusting for the too low levels of output generally generated by imperfect competition. Furthermore, the number of firms is often higher under credit trading, giving less market power to firms and therefore less distorted markets than under permit trading. Under perfect competition, profits are by definition nonexistent. However, under imperfect competition, profits may endure even in the long run. As this paper shows, the effect of the two instruments on firm profits is different, although the precise outcome depends much on the exact configuration of factors. In certain cases, when the number of firms does not increase, credit trading will lead to higher firm profits than no regulation. Oligopolistic competition leads to lower than maximal profits because of the way firms react to each other. In this case, the government can ensure that all firms reduce output, leading to higher prices and higher profits.

The presence of foreign competition leads to additional complications. Although this issue has not been explicitly modelled, it is clear that the choice of instrument can have a pronounced impact on the industry. Any regulation that leads to higher domestic than foreign marginal production costs will have severe consequences for the domestic industry. This holds especially under perfect competition where higher costs will imply that the domestic industry totally disappears. On these grounds, it is likely that governments will be more inclined to use credit trading when there is foreign competition. However, this is an issue that requires more research.

Appendix: Comparative Statics for Perfect Competition

Permit Trading

In this Appendix, the effects on output q, emission level per firm E, product price p and number of firms n of a change in the total limit on emissions L will be derived. By assuming a change from a non-binding limit to a limit that is just binding, this will allow us to analyze the effect of the introduction of regulation.

With permit trading, the following conditions must hold in the long-run

$$P = C_q$$

$$-C_E = R^p \tag{A.1}$$

$$Pq = C(q,E) - R^p E \tag{A.2}$$

$$nE = L$$

$$P = P(nq)$$

Combining (A.1) and (A.2) and differentiating the remaining four equations totally with respect to L gives

$$\frac{dp}{dL} - C_{qE}\frac{dE}{dL} - C_{qq}\frac{dq}{dL} = 0$$

$$q\frac{dp}{dL} = -E\left(C_{EE}\frac{dE}{dL} + C_{qE}\frac{dq}{dL}\right)$$

$$E\frac{dn}{dL} + n\frac{dE}{dL} = 1$$

$$\frac{dp}{dL} = p'\left(q\frac{dn}{dL} + n\frac{dq}{dL}\right)$$

From these we find the following

$$\frac{dq}{dL} = -\left(\frac{qp'\left(EC_{EE} + qC_{qE}\right)}{np'\left(E^2C_{EE} + 2qEC_{qE} + q^2C_{qq}\right) + E^2\left(C_{qE}^2 - C_{EE}C_{qq}\right)}\right) > 0 \tag{18}$$

$$\frac{dE}{dL} = \frac{qp'\left(EC_{qE} + qC_{qq}\right)}{np'\left(E^2C_{EE} + 2qEC_{qE} + q^2C_{qq}\right) + E^2\left(C_{qE}^2 - C_{EE}C_{qq}\right)} > 0 \tag{19}$$

$$\frac{dp}{dL} = \frac{qEp'\left(C_{qE}^2 - C_{EE}C_{qq}\right)}{np'\left(E^2C_{EE} + 2qEC_{qE} + q^2C_{qq}\right) + E^2\left(C_{qE}^2 - C_{EE}C_{qq}\right)} < 0 \tag{20}$$

$$\frac{dn}{dL} = \frac{np'\left(EC_{EE} + qC_{qE}\right) + E\left(C_{qE}^2 - C_{EE}C_{qq}\right)}{np'\left(E^2C_{EE} + 2qEC_{qE} + q^2C_{qq}\right) + E^2\left(C_{qE}^2 - C_{EE}C_{qq}\right)} \tag{21}$$

The signs for the different equations are found through conditions derived by Dijkstra (1999) for the same model. He derives

$$C_{qq}C_{EE} - C_{qE}^2 \geq 0 \tag{22}$$

$$q^2C_{qq} + 2qEC_{qE} + E^2C_{EE} \geq 0 \tag{23}$$

$$qC_{qq} + EC_{qE} > 0 \tag{24}$$

$$qC_{qE} + EC_{EE} < 0 \tag{25}$$

Using these, it is clear from (23) and (22) that the denominator of (18)-(21) is negative. It can then be easily established that $\frac{dq}{dL} > 0$, $\frac{dE}{dL} > 0$ and $\frac{dp}{dL} \leq 0$. However, $\frac{dn}{dL}$ can either be positive or negative, as the first term in the nominator is positive and the second term is negative.

Credit Trading

For credit trading, the following conditions must hold in the long-run

$$p = C_q - R^c\frac{E}{q}$$

$$-C_E = R^c$$

$$pq = C(q, E) + R^c(E - \bar{e}q)$$

$$nE = L$$

$$P = P(nq)$$

Differentiating the above equation totally gives

$$-\frac{dp}{dL} + \left(C_{qq} - \frac{E}{q^2}C_E + \frac{E}{q}C_{qE}\right)\frac{dq}{dL} + \left(C_{qE} + \frac{1}{q}C_E + \frac{E}{q}C_{EE}\right)\frac{dE}{dL} = 0$$

$$q\frac{dp}{dL} = -EC_{EE}\frac{dE}{dL} - \left(EC_{qE} + \frac{E}{q}C_E\right)\frac{dq}{dL}$$

$$E\frac{dn}{dL} + n\frac{dE}{dL} = 1$$

$$\frac{dp}{dL} = p'\left(q\frac{dn}{dL} + n\frac{dq}{dL}\right)$$

From these one can derive the following

$$\frac{dq}{dL} = -\frac{q^3 p' \left(EC_{EE} + qC_{qE}\right)}{\left(nq^2 p' + EC_E\right)\left(E^2 C_{EE} + 2qEC_{qE} + q^2 C_{qq}\right)} \tag{26}$$

$$\frac{dE}{dL} = \frac{q^3\, p' \, \left(EC_{qE} + qC_{qq}\right)}{\left(nq^2 p' + EC_E\right)\left(E^2 C_{EE} + 2qEC_{qE} + q^2 C_{qq}\right)} \tag{27}$$

$$\frac{dp}{dL} = \frac{\left(q\, p'\, C_E\right)\left(E^2 C_{EE} + 2qEC_{qE} + q^2 C_{qq}\right)}{\left(n\, q^2\, p' + E\, C_E\right)\left(E^2 C_{EE} + 2qEC_{qE} + q^2 C_{qq}\right)} \tag{28}$$

$$\frac{dn}{L} = \frac{nq^2 p' \left(EC_{EE} + qC_{qE}\right) + C\left(E^2 C_{EE} + 2qEC_{qE} + q^2 C_{qq}\right)}{\left(nq^2 p' + EC_E\right)\left(E^2 C_{EE} + 2qEC_{qE} + q^2 C_{qq}\right)} \tag{29}$$

Using the conditions given above, it is clear that the denominator of (26)-(29) is negative. It can then be established that $\frac{dq^c}{dL} > 0$, $\frac{dE^c}{dL} > 0$ and $\frac{dp^c}{dL} \leq 0$. However, as with permit trading, the sign of $\frac{dn^c}{dL}$ is not immediately clear since the first term in parenthesis in the nominator is negative, while the second term in parenthesis is positive. Hence, the number of firms can both increase or decrease as a result of regulation.

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