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WORKING PAPER

Environmental policy, policy uncertainty and relocation decisions

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ABSTRACT

We analyse the relocation decision of a monopolist under various assumptions with respect to the difference in environmental policy stringency between the home and foreign country. We show that relocation because of such a difference is highly unlikely in a model that includes uncertainty with respect to the difference in policy stringency. Relocation is however possible if the difference in other production costs is significant. We also show the potential for hysteresis-effects: once relocated, the firm will require a reduction in the difference of environmental policy stringency that is larger than the increase that lead to the relocation decision.

Keywords: Location decision, policy uncertainty, environmental compliance costs, option value

JEL: F12; Q2

1. Introduction

The impact of environmental compliance costs on foreign direct investment and the location decision of firms has been analysed in both theoretical and empirical economic literature. The issue has also been the subject of some debate among environmentalists, industry representatives, free trade advocates and other governmental and non-governmental organisations (Ulph, A. (1996); Jenkins, R. (1998); Keller and Levinson (1999)).

Theoretical literature that deals with localisation decisions includes, among others, Motta and Thisse (1994), Markusen (1995), Ulph (1994), Ulph and Valentini (1997), Rauscher (1997), Petrakis and Xepapadeas (2000) and Xepapadeas (1999). Motta and Thisse (1994) assume a two-country economy with two firms, each of them located in one of the two countries and producing a homogeneous good. They analyse the way in which the environmental policy in a country impacts the location decision of local firms. They assume location independent variable production costs and constant and fixed relocation costs. They also assume that one country does not change its environmental policy stance. They show that relocation depends on the size of the market. If markets are small, relocation is never profitable and a more stringent environmental policy in one country will stop the local producer from exporting to the other country. As market size increases however, relocation becomes a possibility. If markets are sufficiently large, partial relocation might even be considered in the absence of environmental policy. Markusen (1997) models the location decisions by imperfectly competitive firms in the presence of trade barriers when confronted with environmental regulation. He shows that in an environment with multinational firms, the impact of a change in costs on production and trade is smaller compared to the situation with no multilateral firms. He also shows that the form of cost increases is very important. Regulations, which have an impact on fixed costs, can be absorbed through the exit of some firms, whereas a change in the marginal cost is absorbed through changes in production. Ulph and Valentini (1997) use a two-country framework with one upstream and one downstream industry and two firms in each industry. In this way, they introduce an element of economic geography so that both industries might find it advantageous to be located close to one another. Firms face constant marginal costs but have to incur a fixed cost if they wish to relocate to another country. They show that there might be some 'hysteresis effects'. In the absence of environmental policy, all production, both in the up- and downstream industries, is located in the low cost country. If this country increases environmental taxes, firms will not change their location at first. At some level of environmental taxes, two equilibriums emerge but firms do not relocate. If environmental taxes increase further, firms relocate. However, if the low cost country decides to lower taxes, it will have to do so in a significant way as the model moves from one equilibrium in the high cost country to two equilibriums without any relocation. The model only reaches the original equilibrium with all production in the original country if environmental costs are further reduced. Petrakis and Xepapadeas (2000) analyse the relocation decision of a monopolist depending on whether the government can precommit to an emission tax before the relocation decision is taken or not. They show that if the government can precommit to an emission tax, relocation is less likely.

Xepapadeas (1999) introduces uncertainty into a relocation model. He shows that at any time there is a threshold level where, if the environmental policy parameter exceeds this level, relocation will be immediate. As long as the environmental policy parameter does not exceed the threshold level, firms will not relocate.

The model that will be presented in this paper starts from a two-country case where a monopolist, who resides in one country and faces constant average production costs and a fixed relocation cost, decides if relocation of production is profitable. The location of production does not have an impact on the position of the firm on the local market. As in Motta and Thisse (1994) our firm is located in the home country and faces the fixed relocation cost. We do not follow these authors however in their assumption that environmental policy in the foreign country is fixed as we focus on the difference in environmental policy compliance costs, nor do we follow them in their assumption that a firm is located in the foreign country. Following Xepapadeas (1999) we will introduce uncertainty and assume that the difference in environmental policy stringency is uncertain. We do not allow regulatory competition as we focus on the location decision of a monopolist. All variables used in the model are known to or, with respect to uncertainty for instance, perceived by the firm. Our model will be able to capture the impact of trade barriers or transport costs as in Markusen (1997), as well as other cost advantages of production in the home country. As in Ulph and Valentini (1997) we will be able to show the existence of 'hysteresis' effects.

The remainder of the paper is organized as follows: the second paragraph of this paper presents the overall model. The third section looks at the relocation decision if there is 'no' uncertainty in terms of the stringency of environmental policy. The fourth section introduces a model that allows for uncertainty. The fifth section reviews the relocation decision after the introduction of uncertainty. The last section discusses the most important model results. The final section concludes.

2. The model

We will model the decision of a firm along the lines of Petrakis and Xepapadeas (2000) and consider a monopolist[1] who is selling a good in the home market, where he faces linear demand $P(q,t) = b - q(t)$. We will assume that the firm can relocate and supply the home market from some foreign location. It does not have the option to move part of the production to the foreign location. Subscripts h will denote the variables when the firm is located in the home country, while subscripts f will denote foreign country variables. We will assume that the relocation costs are fixed and equal to R. To avoid a situation in which the firm relocates back and forth, we assume that R is sufficiently high to exclude the possibility of firms 'jumping from one country to another'. The monopolist produces $q_i(t);\ i = h,f$ and faces constant returns to scale in production, so marginal production costs are constant and equal to $c_i^p;\ i = h,f$. This assumption is in line with the one used, for instance, in Motta and Thisse (1994). Note that the term marginal production costs should be interpreted broadly and refers to all costs including transport costs and location advantages. Given that we are analysing a monopolist, constant marginal production costs imply that there exists some kind of barrier to entry, for instance, in the form of a patent. We will allow variable production costs to differ across countries.

Emissions, which are a by-product of production, are taxed using a tax rate $t_i(t);\ i = h,f$. The fact that we refer to a 'tax' should not be interpreted as excluding all other environmental policy instruments as for each of them there is a way to transform them into tax equivalents. Following Petrakis and Xepapadeas (2000), total emissions are given by $q_i(t) - a_i(t)$ with $a_i(t)$ the level of abatement in country $i = h, f$ Abatement costs are given by a function $\frac{1}{2} d_i\, a_i(t)^2, d_i > 0$ (see Petrakis and Xepadapeas (2000)). The assumption with respect to abatement costs implies that the firm faces decreasing returns to scale abatement technology, i.e. it is increasingly difficult to reduce emissions if abatement levels increase. Marginal abatement costs equal $d_i a_i$. We will assume that the firm maximizes profits:

$$p_i(t) = \max_{q_i} \left\{ (b - q_i(t))q_i(t) - c_i^p q_i(t) - \frac{1}{2} d_i a_i(t)^2 - t_i(t)(q_i(t) - a_i(t)) \right\} \quad \textbf{(1).}$$

From the first order condition, the optimal output and maximum profits follow:

$$q_i^*(t) = \frac{1}{2}\left(b - c_i^p - t_i(t)\right) \quad \textbf{(2)}$$

$$p_i^*(t) = q_i^{*^2}(t) + t_i(t)a_i(t) - \frac{1}{2} d_i\, a_i(t)^2 \quad \textbf{(3).}$$

[1] The model can be extended to one where two firms engage in Cournot competition.

These results are in line with the ones obtained by Petrakis and Xepadapeas (2000). From (2) it follows that we require that $b - c_i^p > t_i$. If this condition were not satisfied, optimal production in location *i* would equal zero. Throughout this paper we will assume that this condition is satisfied at home. Note from (1) that if there were no emission taxes, the optimal production quantity would be given by

$$\tilde{q}_i = \frac{1}{2}\left(b - c_i^p\right) \qquad \textbf{(2')}$$

The difference between (2) and (2') equals $t_i(t)/2$. Total profits in the absence of environmental policy, $\tilde{p}_i$, equal the square of (2'). The introduction of an emission tax has a double impact on total profits as (3) can be written as (see appendix)

$$p_i(t) = \tilde{p}_i - \left(q_i(t) - a_i(t)\right)t_i(t) - \frac{1}{2} d\, a_i(t)^2 - \frac{1}{4} t_i(t)^2 \qquad \textbf{(3').}$$

The introduction of environmental policy reduces profits. The total emission tax bill, which is the second term on the right hand side, and the total cost of abatement, which is the third term on the right hand side, reduce profits compared to the situation where there is no environmental policy. The last term on the right hand side equals the quantity effect already mentioned in (2').

If the firm is a profit maximizer, it will choose to abate emissions as long as the marginal costs of abatement are less than the marginal tax rate. From this it follows that the firm will abate until

$$t_i(t) = \frac{d\left(\frac{1}{2} d_i\, a_i(t)^2\right)}{d a_i} = d_i\, a_i(t) \qquad \textbf{(4).}$$

The level of abatement follows from (4)

$$a_i(t) = \left[\frac{t_i(t)}{d_i}\right] \qquad \textbf{(5).}$$

We will assume that foreign emission taxes differ from those at home. Let's write the difference as $l(t) = t_h(t) - t_f(t)$. We will further assume that the company operates in a foreign country using comparable production technology and the same abatement technology as in the home country, i.e. $c_h^p = c_f^p + w$ and $d_h = d_f = d$. The difference in variable production costs (w) can be due to lower factor costs in the foreign country (which would increase the difference), the existence of transport costs, trade barriers or other costs, for instance, related to the fact that production is not located in the market where the goods are sold (all of these examples would lower the difference). Using these assumptions, the appendix shows that the home total profit function can be written as

$$p_h = p_f - q_f(w + l) + \frac{1}{4}\left(w^2 + l^2\right) + \frac{1}{2}wl + \frac{l}{d}\left(t_f + \frac{1}{2}l\right) \qquad \textbf{(6)}$$

which means that the excess profits from production abroad compared to production at home are equal to

$$p_f - p_h = p_e = q_f(w + l) - \frac{1}{4}\left(w^2 + l^2\right) - \frac{1}{2}w\,l - \frac{l}{d}\left(t_f + \frac{1}{2}l\right) \qquad \textbf{(7).}$$

There are three mechanisms that have an impact excess profits. Higher production levels in the foreign location will have an impact on prices. The combined impact of higher production levels and lower prices equals the first three terms on the right hand side of (7). The last term accounts for the differences in abatement costs and emission taxes. This is necessary because the first three terms do not fully account for abatement. With respect to the last term, first note that $\frac{l}{d} = \frac{t_h}{d} - \frac{t_f}{d} = a_h - a_f$, i.e. the difference between home and foreign abatement. The first three terms on the right hand side of (7) assume that the advantage of relocating production in terms of this difference equals l. The emissions, which are abated at home, would be taxed in the foreign country. Note also that the first term on the right hand side of (7) implies that there is an advantage with respect to the first a_f units that are abated at home. The last term on the right hand side of (7) eliminates these advantages that were wrongly introduced in the first term.

From (7) it follows that

$$\frac{\partial p_e}{\partial l} = \left(q_f - a_f\right) - \frac{1}{2}(w + l) - \frac{l}{d} = \left[q_f - \frac{1}{2}(w + l)\right] - \left(a_f + \frac{l}{d}\right) \qquad \textbf{(8)}$$

and that

$$\frac{\partial p_e}{\partial l} = 0 \Leftrightarrow \bar{l} = \frac{2d\left(q_f - a_f\right) - dw}{d + 2} \qquad \textbf{(9)}$$

$$\frac{\partial^2 p_e}{\partial l^2} = -\frac{1}{2} - \frac{1}{d} = -\left(\frac{d + 2}{2d}\right) < 0 \qquad \textbf{(10).}$$

As long as $l < \bar{l}$, the first derivative in (8) will be positive. This condition is highly likely to be satisfied. From (8) it follows that the decreasing excess profits once the difference in emission taxes become very large, i.e. a negative first derivative, are due to the fact that the profits at home are affected by the fact that all efforts are directed towards abatement and emission levels equal zero. To show this, remember that the emission tax at home equals the sum of l and the emission tax abroad. If we use the expression for l in (9) and add the emission tax abroad, we can see that in terms of the emission tax at home, (9) implies

$$t_f + \overline{l} = \frac{d\,t_f + 2t_f}{d+2} + \frac{2d\left(q_f - a_f\right) - dw}{d+2} = \frac{2d\,q_f - 2d\,a_f - dw + d\,t_f + 2t_f}{d+2}$$

with $d\,a_f = t_f$. Noting that $\tilde{q}_h = \frac{1}{2}\left(b - c_f^p\right) - \frac{1}{2}w$ this yields

$$t_f + \overline{l} = \frac{2d\,\tilde{q}_h}{d+2}$$

which, in terms of abatement levels, yields $\overline{a}_h = \frac{2}{d+2}\tilde{q}_h$ and, in terms of the production level, yields $\overline{q}_h = \tilde{q}_h - \frac{1}{2}\left(t_f + \overline{l}\right) = \frac{2}{d+2}\tilde{q}_h$. Given the assumptions with respect to emissions, this implies a zero emission level. From (8) - (10) it follows that, as the gap between the emission taxes widens, the excess profits from locating abroad increase but they do so at an increasingly slower pace. Note also from (8) that the impact of the difference in emission taxes depends on the difference in marginal production costs as

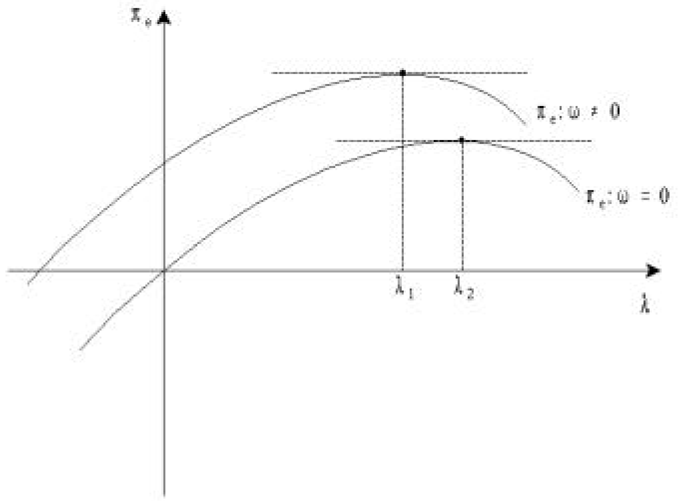
$$\frac{\partial p_e}{\partial l\,\partial w} = -\frac{1}{2} \qquad \textbf{(11)}$$

i.e. for a given difference in environmental taxes, an increase in the spread between marginal production costs has a negative impact on the excess profits.

At home, emissions equal $q_h - a_h$. When the firm produces in the foreign location, they equal $q_f - a_f = \left(q_h + \frac{1}{2}(w + l)\right) - \left(a_h - \frac{l}{d}\right) = q_h - a_h + \frac{1}{2}(w + l) + \frac{l}{d}$. The extra emissions due to relocation equal the last two terms on the right hand side of (7). Note that the first derivative of the extra emissions with respect to l equals $\frac{d+2}{2d}$.

Figure 1 shows a plot of two excess profit functions. The dotted line represents the function if the difference in marginal production costs equals 0, the full line assumes a non-zero difference in marginal production costs. From (9) it can be seen that the difference between l_1 and l_2 equals $\frac{dw}{d+2}$.

Figure 1: Excess profits from relocation abroad



3. The decision to relocate

Using the model presented so far, it is possible to analyse the relocation decision of a firm. If r is the discount rate, then the value of relocation abroad, assuming an infinitely lived factory, equals the sum of all excess profits. If we assume that none of the variables change over time, an assumption that we will afterwards relax, the value of the relocation project is given by $V_1(p_e, r)$:

$$V_1(p_e, r) = \int_0^{\infty} p_e e^{-rt} dt \qquad \textbf{(12).}$$

If relocation were free, the optimal relocation rule would be to invest abroad if the value of the relocation project is positive. As none of the variables are allowed to change, the optimal investment rule can be restated as: relocate if the excess profit is positive.
Obviously, the zero investment cost assumption needs relaxing. If we assume that the investment costs are fixed and equal to R, the net present value (NPV) criterion suggests relocation if

$$V_1(p_e, r) = \int_0^{\infty} p_e e^{-rt} dt = \frac{p_e}{r} > R \qquad \textbf{(13)}$$

i.e. if the investment cost which is required to relocate is less than all future profits combined. Condition (13) implicitly defines a line in the $(l, V_1(p_e, r))$ space that represents the maximum relocation cost for various values of l and has the following properties

$$R_{\max} = \frac{p_e}{r} = \frac{1}{r}\left[q_f\left(w + l\right) - \frac{1}{4}\left(w^2 + l^2\right) - \frac{1}{2}w\,l - \frac{l}{d}\left(t_f + \frac{1}{2}\,l\right)\right] \qquad \textbf{(14a)}$$

$$\frac{\partial R_{\max}}{\partial l} = \frac{\partial\left(\frac{p_e}{r}\right)}{\partial l} = \frac{1}{r}\left\{\left[q_f - \frac{1}{2}\left(w + l\right)\right] - \left(a_f + \frac{l}{d}\right)\right\} = \frac{1}{r}\left(q_h - a_h\right) \qquad \textbf{(14b)}$$

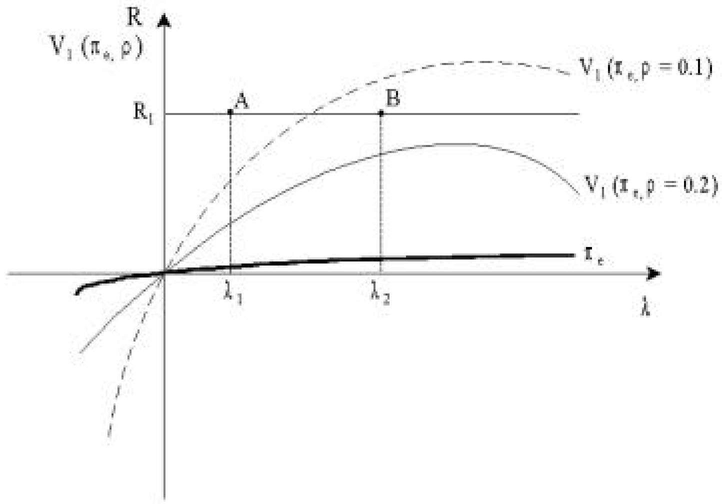
$$\frac{\partial^2 R_{\max}}{\partial l^2} = \frac{\partial^2\left(\frac{p_e}{r}\right)}{\partial l^2} = \frac{1}{r}\left(-\frac{1}{2} - \frac{1}{d}\right) = -\frac{1}{r}\left(\frac{d+2}{2d}\right) \qquad \textbf{(14c).}$$

The maximum relocation cost defines a boundary in the (l , $V_1(p_e, r)$) space. If the value of the relocation project is higher than the maximum relocation cost, the firm will relocate. If the value is smaller, the firm will choose to keep production in the home country. With the exception of the discount factor $\frac{1}{r}$, equations (14a), (14b) and (14c) are equal to (7), (8) and (10). As can be seen from equations (14a)-(14c) and from equation (13), the introduction of a discount factor does not change the overall shape of the curve. A lower discount rate increases the value of the project, which implies a wider range of values for l for which it is optimal to relocate.

From figure 2, it is obvious that the likelihood of relocation increases for the smaller discount rates. If we assume for instance that the discount rate equals 10%, then the dotted line represents values of the investment project given by (12). The horizontal line equals the investment cost (R_1). If a relocation project can be represented in terms of l and its value (equation (13)) by point A, A: ($l_1, V_1\left(p_e(l_1), r\right)$) in figure 2 and if A implies a relocation costs equal to R_1, it would be optimal to keep production at home as the value of the project is less than the investment cost. A project that can be represented by point B, B($l_2, V_1\left(p_e(l_2), r\right)$) in figure 2 is one for which it is optimal to relocate, as the value of the relocation is higher than the investment costs. If we assume that the discount rate equals 20%, it follows from figure 2 that neither project would be considered. The case in which investment costs are 0 can be drawn with the horizontal line representing investment costs equal to the horizontal axe. Also note that the position of the line that represents the value of the excess profits from relocating abroad also depends on the difference in production costs. From figure 1 it can be seen that lower production costs in a foreign location will increase the value of relocation for a given difference in emission taxes.

The introduction of the fixed investment costs reduces the probability of relocation, as a number of projects do no longer have a positive net present value. The probability of relocation increases as the fixed investment costs decrease and as the discount rate is lower.

Figure 2: Value of a project under various discount rates



The model that was presented so far is static in the sense that no variables are allowed to change over time. Obviously this is somewhat of a strong assumption as it implies that a monopolist looking into a relocation project expects that the emission taxes for instance will not change in the future. In order to relax this assumption, we will introduce a dynamic element into the model. We will do so in two steps. First, we will extend the model that was already presented above. Secondly, we will analyse the relocation decision in the extended model that includes uncertainty and compare it with the relocation decision in the simple model.

4. A model for the excess profits

In order to add some variability to the model already presented, we will model the difference in emission taxes as a geometric Brownian motion with instantaneous expected drift equal to $a\,l$ and variance $s^2 l^2$

$$d\,l = a\,l\,dt + s\,l\,dz \qquad \textbf{(15)}$$

where dz is the increment of a Wiener process, equal to $e\sqrt{dt}$ with zero mean: $E[dz] = 0$ and unit variance: $V[dz] = 1$. The geometric Brownian motion in (15) says that the expected change in the difference between the emission taxes equals a fixed percentage a. There is however some uncertainty with respect to this change. This uncertainty is modelled through the addition of $s l dz$. The choice of the geometric Brownian motion makes sense if we assume that the monopolist does not have perfect foresight. The firm has some expectation with respect to the future difference but does not have certainty in that respect. The firm's assessment of the trend in the difference between emission taxes could be based on, for instance, the fact that the firm works under the assumption that income differentials between two countries can converge and that environmental quality is a luxury good. If this is the case, then two countries that are comparable except for their income level will have different emission taxes: the poor countries' emission taxes will be lower. As income grows however, this difference will change over time as the demand for environmental quality rises with income. As income grows faster in the poor country, demand for environmental quality will do so as well. Once income levels are fully equal and the difference between emission taxes vanishes, it is reasonable to assume that this situation is more or less stable. The speed with which differences in emission taxes converge will depend on a number of other variables. First of all, it will depend of the speed with which income converges. Barro and Sala-i-Martin (1995) or Barro (1997) have shown that income convergence between two countries is conditional on the differences in, for instance, measures of human capital, political stability and the existence of functioning markets. With respect to demand for environmental quality, Verbeke (2001) has shown that it seems to depend not only on the income level, but on the level of damage which pollution causes as well. If the firm expects convergence and assumes that environmental quality is indeed a luxury good, it would expect the difference in emission taxes to diminish ($a < 0$). The instantaneous variance takes into account the fact that this expectation is conditional. There might be uncertainty with respect to, for instance, the conditions that cause income to converge or with respect to the size of the income elasticity of demand for environmental quality. This uncertainty should be reflected in the instantaneous variance. Note that the firm could choose not to accept conditional convergence or the fact that environmental quality is a luxury good. If this is the case, it could expect the difference to widen ($a > 0$) or to stay more or less constant ($a = 0$). The arguments with respect to conditional convergence or the luxury nature of environmental quality were only used as an example to illustrate one out of many possibilities how the firm could build expectations with respect to future differences in environmental stringency.

The assumption with respect to the geometric Brownian motion also implies that once the foreign emission tax levels have 'caught up' with those at home, emission taxes stay at comparable levels. This does not seem to be an assumption that is too restrictive. If two countries are comparable in terms of environmental stringency, in all likelihood, one could assume that they are more or less comparable in terms of income or responsiveness of government to popular environmental concerns as well.

From (15) it is possible to calculate the expected difference in emission taxes as well as the variance of the difference. The expected difference is given by (Dixit and Pindyck (1994)):

$$\mathrm{E}[l(t)] = l_0 e^{a t} \tag{16}$$

$$\mathrm{V}[l(t)] = l_0^2 e^{2a t}\left[e^{s^2} - 1\right] \tag{17}$$

with l_0 equal to the current value of the difference between emission taxes.

The value of relocation depends on the excess profits from relocating to a foreign country. We have to assess the impact of the change in the difference in emission taxes on the excess profits from relocation. Using Ito's lemma (Neftci (2000)), the change in the excess profits can be written as

$$dp_e = \frac{\partial p_e}{\partial l} dl + \frac{1}{2}\frac{\partial^2 p_e}{\partial l^2}(dl)^2 \tag{18}.$$

Substituting (8), (10) and (15) into (18) yields

$$dp_e = \left\{\left[q_f - \frac{1}{2}(w + l)\right] - \left(a_f + \frac{l}{d}\right)\right\} dl + \frac{1}{2}\left\{-\frac{1}{2} - \frac{1}{d}\right\}(dl)^2 \tag{19}$$

$$dp_e = \left[(q_h - a_h)\, a l - \left(\frac{d+2}{4d}\right) s^2 l^2\right] dt + (q_h - a_h) s l \, dz \tag{20}$$

i.e. the change in the excess profits is a Brownian motion with instantaneous drift $\left[(q_h - a_h) a l - \left(\frac{d+2}{4d}\right) s^2 l^2\right]$ and instantaneous variance $(q_h - a_h) s l$. As the Wiener process in (20) is equal to the one in (15), both the excess profits and difference in emission taxes are affected by the same source of uncertainty. From (20), a geometric Brownian motion for p_e similar to the one in (15) can be constructed as

$$dp_e = \begin{cases} \left(\frac{\hat{a}}{p_e}\right) p_e dt + \left(\frac{\hat{s}}{p_e}\right) p_e dz = a' p_e dt + s' p_e dz & \Leftrightarrow p_e \neq 0 \\ 0 & \Leftrightarrow p_e = 0 \end{cases} \tag{21}$$

with

$$\hat{a} = (q_h - a_h)\, a l - \left(\frac{d+2}{4d}\right) s^2 l^2 \tag{22}$$

$$\hat{s} = (q_h - a_h) s l \tag{23}.$$

From (22) and (23) it can be seen that, for normal values of l, i.e. values which do not involve zero emissions in the home country, $a' < a$ and $s' < s$ as $(q_h - a_h)\, l < p_e$ and $\left(\frac{d+2}{4d}\right) s^2 l^2 > 0$. Note also from (22) that a' takes into account the various impacts of a change in the difference between emission taxes as $\left(\frac{d+2}{4d}\right) l^2$ can be written as $\frac{1}{4} l^2 + \frac{1}{2} l \frac{l}{d}$. Abatement is taken into account as $\frac{1}{2} l$ equals the difference in average abatement costs and $\frac{l}{d}$ the difference in abatement. We have also shown that $\frac{1}{4} l^2$ equals the impact on profits due to a change in production levels. The difference in emission taxes is taken into account through $(q_h - a_h)\, l$.

From the discussion with respect to the excess profits from locating abroad it shouldn't come as a surprise that $a' < a$ or $s' < s$ as a change in the difference in tax rates has different effects. First of all, if we assume that the growth rate of the difference in emission taxes is negative, abatement costs in the foreign country increase faster than the abatement costs at home. Although the higher prices that can be charged through lower production levels will reduce part of the impact of higher abatement costs on foreign profits, the excess profits will decline faster than the difference in emission taxes. If, on the other hand, the difference in emission taxes increases, either through the fact that the foreign country reduces emission tax rates or through the increase of emission taxes at home, the impact of the change in relative abatement costs will be partly offset through the impact of production levels on the price.

5. The decision to relocate under changing excess profits

Before we move on to look at the decision to relocate using the full model presented in equation (21), let's take a look at what happens when we only take into account the fact that the difference in emission taxes changes at a steady and certain pace. Although the majority of cases will lack certainty, there might be a number of examples where (near) certainty can be assumed. If a country ratifies an environmental treaty that establishes environmental quantity standards to be met at specific moments in time, there would be less uncertainty in terms of future differences in environmental policy stringency. Note also that most Central and Eastern European countries that have applied for EU membership are, through the pre-enlargement strategy which requires them to comply with the acquis communautaire using a specific timetable, promising to reduce differences in environmental policy stringency establishing relative certainty with respect to their compliance.

Using (21), total excess profits from investing abroad can be written as

$$\mathrm{E}[p_e(t)] = p_e(t_0)e^{a't} \tag{24}$$

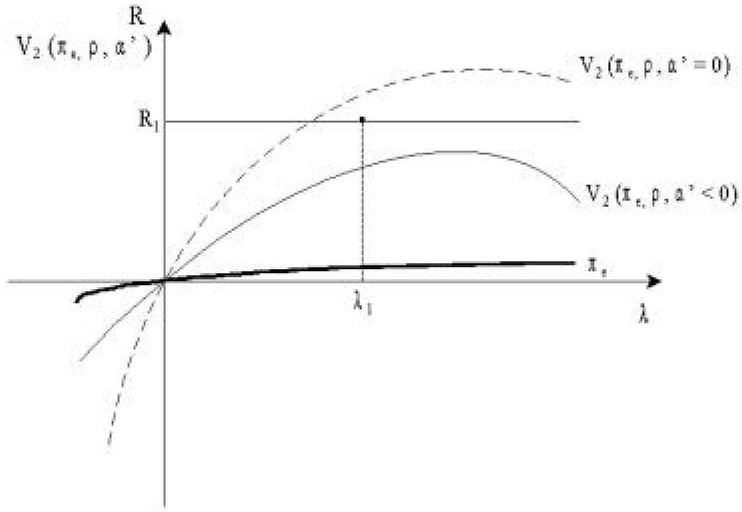
with t_0 indicating the current date.

Using (24) we can value the project as

$$V_2(p_e, r, a') = \int_0^\infty p_e(t)e^{-rt}dt = \int_0^\infty p_e(t_0)\, e^{(-r+a')t}dt = \frac{p_e(t_0)}{r-a'} \tag{25.}$$

If $a' < 0$ with $s' = 0$, the company will either relocate immediately or never relocate at all (see also Dixit and Pindyck (1994)). To see this, notice that at some time in the future, t_1, the value of the project will be less than the value at t_0 as $p_e(t_0) > p_e(t_1)$. As the relocation cost does not change over time, the net present value of relocation will never exceed the investment cost if this isn't the case at t_0. Figure 3 compares the case for $a' < 0$ with the one where $a' = 0$ that was already drawn for two discount rates in figure 2. As can be seen from this figure, the introduction of a downward sloping trend in the difference in emission taxes reduces the probability of relocation. If we assume for instance that the difference in environmental policy stringency is given by l_1 and the cost of relocation by R_1, the firm would decide to relocate under the first net present value criterion presented in (13). The introduction of a negative trend in the difference in emission taxes changes this decision and induces the firm to produce in the home country. From figure 1, we know that lower marginal production costs increase the value of the project. However, in the presence of environmental policies that tend to converge and assuming that the gap in marginal production costs does not widen, the overall conclusion still stands: unless relocation is profitable now, the firm will produce at home and keep its production local.

Figure 3: Relocation decision with negative trending spread in emission taxes



The case for $a' = 0$ with $s' = 0$, has already been presented in figure 2 so we can turn to the case where $a' > 0$ with $s' = 0$, i.e. the difference in emission taxes is growing at a steady pace. We will also assume that the difference in emission taxes is less than the value given by (9). As was shown there, this was the level that implied zero emissions for the home country. Although in theory it could be considered, we will restrict ourselves to the situation where the difference is such that emissions are still relevant. Since the value of the relocation project, $V_2(p_e, r, a')$, is a constant multiple of the excess profits from relocation, it increases with instantaneous growth rate a' (Pennings and Sleuwaegen (2000)). Opposite to the case where the growth rate was negative, the firm could either be in a situation in which relocation is the best strategy at present or in one where relocation will be postponed. In the latter case, relocation might become the best strategy some time in the future. Following Dixit and Pindyck (1994), the firm should relocate now if

$$V_2(p_e, r, a') = \frac{p_e(t_0)}{r - a'} > \frac{r}{r - a'} R \qquad \textbf{(26)}$$

which is equal to the relocation rule with $a' = 0$ as

$$\frac{r - a'}{r} \frac{p_e(t_0)}{r - a'} > \frac{r - a'}{r} \frac{r}{r - a'} R \Rightarrow \frac{p_e(t_0)}{r} > R \qquad \textbf{(27).}$$

If the current value of relocation is less than the investment costs, the opportunity to relocate still has some value, as relocation might in fact become the profitable strategy. As shown by Dixit and Pindyck (1994), the value of the relocation opportunity at some time T in the future equals

$$\left(V_2 e^{a'T} - R\right)e^{-rT} \tag{28}$$

i.e. the net present value of the project at time T discounted to the present. Maximizing (28) with respect to T yields for the optimal time to relocate if relocation is not immediate,

$$T^* = \frac{1}{a'}\ln\left(\frac{rR}{p_e(t_0)}\right) \tag{29}$$

which equals 0 (i.e. relocate immediately) if (27) can be written as an equality. Substituting (29) into (28) yields the value of the opportunity to relocate

$$\left(\frac{a'R}{r-a'}\right)\left(\frac{p_e(t_0)}{rR}\right)^{\frac{r}{a'}} \quad \textbf{(30).}$$

It is straightforward to show that the optimal relocation rule in (27) only yields a relocation decision if the value of the relocation project is higher than the sum of the relocation cost R and the value of the relocation opportunity that is given up if the firm relocates. Add the relocation costs, R, to the value of the opportunity to relocate (30) to obtain the total relocation cost that takes into account the value of the option to relocate:

$$R + \left(\frac{a'R}{r-a'}\right)\left(\frac{p_e(t_0)}{rR}\right)^{\frac{r}{a'}} \quad \textbf{(31).}$$

The value of the investment project should at least equal the costs given in (31), i.e.

$$\frac{p_e(t_0)}{r-a'} = R + \left(\frac{a'R}{r-a'}\right)\left(\frac{p_e(t_0)}{rR}\right)^{\frac{r}{a'}} \Leftrightarrow p_e(t_0) = rR - a'R + a'R\left(\frac{p_e(t_0)}{rR}\right)^{\frac{r}{a'}} \quad \textbf{(32).}$$

If (27) is satisfied with equality, then (32) yields the optimal investment rule with equality.

The introduction of a trend in the difference in emission taxes alters the relocation decision if the trend is negative. Relocation is either worthwhile today or it will never be. If the firm is certain that the differences in emission taxes will diminish, it will either relocate now or it will never relocate at all. For the firms located within the EU, this

seems to suggest that relocation for environmental reasons to Central and Eastern European countries that have applied for membership is no longer an option. Note that the introduction of a negative trend also reduces the likelihood of immediate relocation. When the difference in emission taxes widens, it has been shown that relocation might become worthwhile in the future. The opportunity to relocate has a positive value and should be added to the relocation costs in order to assess total relocation costs.
In both cases, the probability of relocation increases as the difference in marginal production costs grows, the relocation costs increase and the discount rate decreases. The difference in marginal production costs increases the excess profits from relocation, which in turn increases the value of the relocation project in each time period in the future. A lower discount rate increases the value of future profits.

In a last step we will introduce uncertainty into the model through the inclusion of the instantaneous variance in equation (23). The introduction of some uncertainty means that at times, although the trend in the difference between emissions is negative (positive), the change might actually be positive (negative). To value the opportunity to invest, we'll follow the contingent claim approach discussed in Dixit and Pindyck (1994). The contingent claim approach assumes that there is some traded asset or basket of assets that correlates perfectly with the excess profits from relocation. As shown in (30), the value of the opportunity to relocate depends on the value of the relocation project. Using Ito's Lemma, we could model the change in the value of the opportunity to relocate. As Neftci (2000) notes and as can be seen from (18) this means that the source of uncertainty that affects the change in the value of the project is the same as the one that affects the value of the relocation opportunity. If both the value of the relocation project and the value of the relocation opportunity depend on the same source of uncertainty, it is possible to form a risk-free portfolio that yields the risk free rate, r.
This approach allows us to define the discount rate. If there are two assets with exactly the same risk profile, they should earn the same expected return. If 2 assets have different risks but the same expected return, arbitrageurs would step in and exploit this difference for a profit. All assets with the same risk profile should earn the risk free rate plus some reward for the risk that is being taken. According to the capital asset pricing model, the expected return on a risky asset, and thus on the project to relocate the operations from one country to another, as well as on the asset which is affected by the same source of risk, should equal m, which is given by

$$m = r + s' r_{p_e m} f \quad \textbf{(33)}$$

with $f; f > 0$ equal to the market price of risk and $r_{p_e m}$ the coefficient of correlation between the risky asset and the market. The term $s' r_{p_e m}$ equals the amount of 'market' risk the project involves. From (21) we know that the change in the excess profits equals a'. From (33) we know that the total return should equal m. The difference between both, $k = m - a'$ can, as Dixit and Pindyck (1994) point out, be seen as the "*opportunity cost of delaying*" the relocation of the operations of the firm to another country. If the total return on the relocation project equals m, part of it will come from the change in the value of that project, i.e. part of it will equal a'. The other part of the return should come from the payout of dividends from the project. The part that comes in the form of a dividend equals k. We will assume that $k > 0$, i.e. that $m > a'$. The assumption is fairly straightforward. If a' is very large, the firm highly values the opportunity to invest as for each period the firm postpones relocation, the value of the project increases as the emission taxes abroad as well as the abatement costs, relative to those at home, fall. Postponing the relocation decision under these circumstances makes sense, as the relocation project will be more valuable in the future.

In order to value the relocation project we will construct a portfolio of the project itself as well as a short position in an asset with the same risk profile as the excess profits. The portfolio is risk-free and should return the risk free rate r. The holder of the relocation project will receive a dividend equal to p_e, the short position costs kp_e for each unit. From these assumptions, it can be shown that the value of the investment project, $V_3(p_e, m, a', s')$ is given by the solution to the differential equation

$$\frac{1}{2} s'^2 p_e^2 \frac{\partial^2 V_3}{\partial p_e^2} + (r - k) p_e \frac{\partial V_3}{\partial p_e} - r V_3 + p_e = 0 \qquad \textbf{(34).}$$

Ruling out bubbles, the value of the relocation project equals (Dixit and Pindyck (1994))

$$V_3(p_e, m, a', s') = \frac{p_e}{m - a'} \qquad \textbf{(35)}$$

which is equal to the expected value of the project using the discount rate in (33).

The value of the investment opportunity can be calculated as the solution to a differential equation that is similar to the one in (34). If we write the value of the opportunity to relocate as $F(p_e)$, the differential equation becomes

$$\frac{1}{2} s'^2 p_e^2 \frac{\partial^2 F}{\partial p_e^2} + (r - k) p_e \frac{\partial F}{\partial p_e} - r p_e = 0 \qquad \textbf{(36)}$$

and the solution equals

$$F(p_e) = B_1 p_e^{b_1} + B_2 p_e^{b_2} \qquad \textbf{(37).}$$

Equation (37) can be solved using the following conditions

$$F(0) = 0 \tag{38a}$$

$$F(p_e^*) = V_3(p_e^*) - R \tag{38b}$$

$$\frac{dF(p_e^*)}{dp_e} = \frac{\partial V_3(p_e^*)}{\partial p_e} \tag{38c}$$

Condition (38a) says that the opportunity to relocate should have no value if the excess profits are zero. Conditions (38b) and (38c) are the value-matching and smooth pasting conditions. The value matching condition in (38b) says that the value of the opportunity to relocate should equal the net benefits from relocation when the excess profits are equal to the level at which relocation becomes profitable for the first time. If the excess profits change from that level, the smooth pasting condition (38c) says that the value of the opportunity to invest should change in the same way as the net benefit from relocation, which is, given the assumption, equal to the change in the value of the relocation project. To determine values for b_1 and b_2, we can substitute Bp_e^b into (36) to obtain

$$\frac{1}{2} Bs'^2 p_e^2 (b-1) bp_e^{b-2} + (r-k) Bp_e bp_e^{b-1} - rBp_e^b = 0 \tag{39}$$

which yields

$$\frac{1}{2} s'^2 (b-1) b + (r-k) b - r = \frac{1}{2} s'^2 b^2 + \left(r - k - \frac{1}{2} s'^2 \right) b - r = 0 \tag{40}$$

Equation (40) can be solved for the beta's to yield solutions for b_1 and b_2

$$b_1 = \frac{1}{2} - \frac{r-k}{s'^2} + \sqrt{\left(\left(\frac{r-k}{s'^2} \right) - \frac{1}{2} \right)^2 + \frac{2r}{s'^2}} \tag{41a}$$

$$b_2 = \frac{1}{2} - \frac{r-k}{s'^2} - \sqrt{\left(\left(\frac{r-k}{s'^2} \right) - \frac{1}{2} \right)^2 + \frac{2r}{s'^2}} \tag{41b}$$

with $b_1 > 1$ and $b_2 < 0$. With $b_2 < 0$ and given that the opportunity to relocate would become very large as $p_e \to 0$, given (38a) B_2 must equal zero. This leaves $B_1 p_e^{b_1}$ to be solved. From the value-matching condition (38b) and smooth-pasting condition (38c) we know that

$$B_1 p_e^{*b_1} = \frac{p_e^*}{m - a'} - R \tag{42a}$$

$$b_1 B_1 p_e^{*\,b_1-1} = \frac{1}{m-a'} \qquad \textbf{(42b).}$$

The ratio of (42a) to (42b) yields

$$\frac{1}{b_1} p_e^* = p_e^* - (m-a')R \qquad \textbf{(43).}$$

From (43) the excess profits can be written as

$$p_e^* = \frac{b_1(m-a')}{b_1-1} R \qquad \textbf{(44).}$$

Substituting (44) into (37) and using from (42b) the fact that $B_1 = \frac{p_e^{1-b_1}}{b_1(m-a')}$ yields the value of the opportunity to relocate $\frac{1}{b_1-1} R$.

From (44) and using (35), the value of the project to relocate using the minimal excess profits, equals

$$V_3^*\left(p_e^*, m, a', s'\right) = \frac{b_1}{b_1-1} R \qquad \textbf{(45).}$$

If the value of the relocation project is larger than the threshold value given in (45), the firm will relocate. If this is not the case, the firm will opt to stay at home. The optimal relocation rule can be summarised as follows: the firm should relocate if

$$V_3(p_e, m, a', s') > V_3^*\left(p_e^*, m, a', s'\right) \Rightarrow \frac{p_e}{m-a'} > \frac{b_1}{b_1-1} R \Rightarrow \frac{p_e}{m-a'} \frac{b_1-1}{b_1} > R \qquad \textbf{(46).}$$

Again notice from the value of the option to relocate and the relocation cost that (45) compensates for both the option value as well as the relocation costs.

6. Discussion

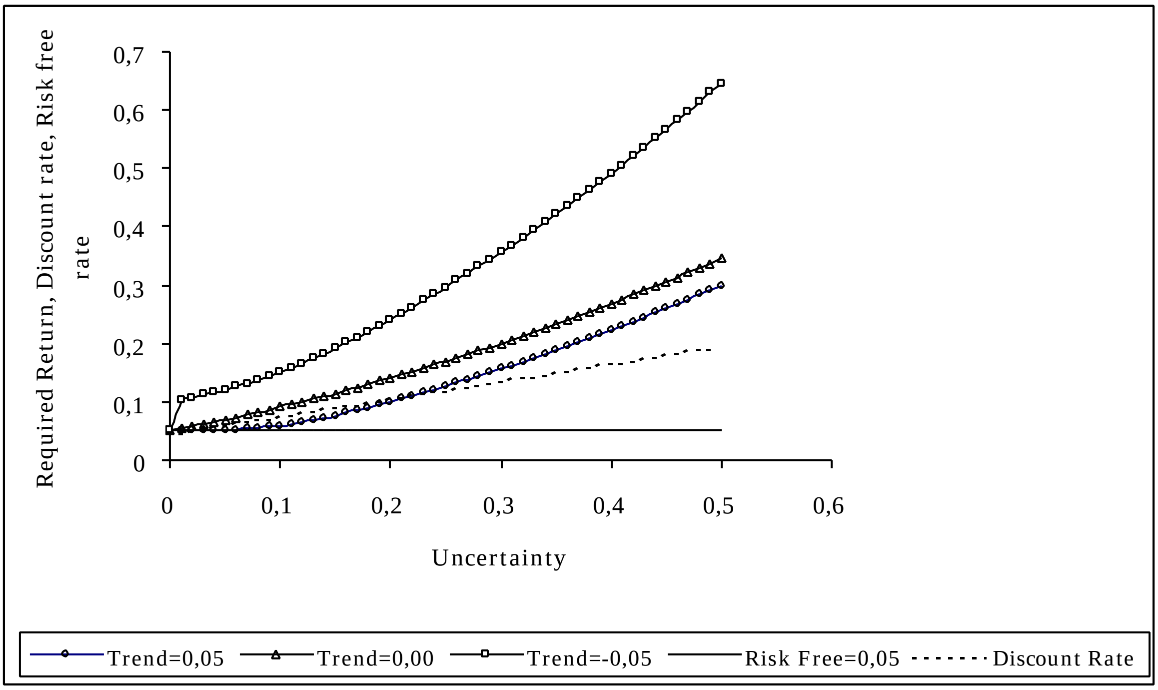
To compare the various cases, we'll show how the excess profits relate to the investment costs both at t_0 and, if applicable, at the time investment will be undertaken for the 3 models we have considered. Recall that under the net present value criterion, the firm will relocate if the excess profits from relocation are higher than rR, i.e. the return on the relocation project, $\frac{p_e(t_0)}{R}$, should equal at least the risk free rate, r . Under the net present value rule, the firm will either relocate immediately or it will never relocate at all. When we introduce a trend in the excess profits function through the introduction of a trend in the difference in emission taxes, we can distinguish the case where the trend is negative and the case where the trend is positive. If the trend is negative, the firm demands a return on investment that equals the risk free rate as well as a compensation for the reduction in the excess profits as the return on the relocation project must equal at least $r - a' > r$. Similar to the case under the net present value criterion, the firm will either relocate immediately or it will never relocate. If the excess profits from relocation increase as time passes, the firm still requires a return on investment that equals the risk free rate. Contrary to the case where the excess profits exhibit a negative trend, the required return on investment does not include the trend when it is positive. The reason lies in the fact that the firm requires a compensation for giving up the opportunity to postpone relocation. The value of the opportunity to relocate was calculated in (30). If at t_0 excess profits are smaller than those that would be required to reach the minimum return on investment r, the firm will not relocate. The minimum excess profits equal those using the net present value criterion. If, at present, relocation is not the best strategy, it might become the best strategy some time in the future if the excess profits are increasing (see (29)). Introducing uncertainty increases the required return on investment in two ways. To see this, note from (46) and (33) that the required return on investment equals

$$\frac{p_e}{R} = (m - a')\frac{b_1}{b_1 - 1} = (r - a')\frac{b_1}{b_1 - 1} + s' r_{p_e m} f \frac{b_1}{b_1 - 1} \qquad \textbf{(47).}$$

From (47) it can be seen that the required return on investment is higher after the introduction of uncertainty unless the trend in the excess profits is positive and exceeds the factor $\frac{1}{b_1} r + s' r_{p_e m} f$. This is highly unlikely. As a' is high, either m is high or q is low. For a given level of the risk free rate, the first possibility seems to suggest that the uncertainty with respect to the change in the excess profits (and thus with respect to the change in the difference in emission taxes) is high, which reduces the probability that the trend in excess profits exceeds the level which would result in a lower required return on investment. A low q on the other hand increases the value of the opportunity or the option to relocate as the opportunity cost of holding on to it is small, which translates into a small beta. Both these situations seem to be in line with economic 'intuition'. Recall that the trend in excess profits was derived from the trend in emission taxes. The total amount of emissions falls as emission taxes rise. If environmental quality is a luxury good, i.e. if the income elasticity of demand for environmental quality exceeds 1, then demand for environmental quality should be higher in rich countries compared to poor countries. However, based on the conditional convergence hypothesis (Barro and Sala-i-Martin (1995)), income grows faster in poor countries compared to rich countries. If that is indeed the case, demand for environmental quality should also rise faster in poor countries. This results in a negative trend in the difference in emissions and in the excess profits from relocation. A positive trend in the difference between emission taxes could result from the situation where either the rich country continues to implement increasingly stringent emission taxes or because the poor country does not implement or even lowers emission taxes or a combination of both. In each of these cases, at least one country has environmental policies that are ‘out of line’ with income, which could correct itself in the long run. The latter situation creates uncertainty or reduces the opportunity cost of investment. As Barro and Sala-i-Martin (1995) and numerous others have shown, the growth rate is positively correlated with the level of human capital, the existence of functioning markets, stable political regimes, etc.. A rising difference in emission taxes could indicate that the ‘poor’ country experiences low growth. From the conditional convergence hypothesis, it is likely that the ‘poor’ countries does not have adequate human capital, functioning markets or stable political regimes. Given that environmental quality can be considered a luxury good, it might also be indicative of the fact that the country does not have a ‘political regime’ that translates increased demand for environmental quality into legislation. The first case increases the uncertainty; the latter case increases the opportunity cost as the ‘perceived’ trend in the difference is considered ‘abnormal’ (i.e. the perceived a' is different from the ‘real’ long run a'). A similar argument might be made with respect to the case where the difference increases because of an increasingly strict emission tax regime in the ‘rich’ country.

To illustrate the effect of uncertainty, figure 4 shows the required return as a function of uncertainty assuming the correlation coefficient in (33) equals 1, the risk free rate equals 5% and the market price of risk, i.e. the excess return per unit of volatility, equals 0,30. These assumptions lead to a required return of 11% on an asset whose volatility equals 20%. From figure 4 it is evident that uncertainty as well as the future direction of the difference in emission taxes are important variables in determining the likelihood of relocation.

Figure 4: Required return for various models*



(*)"Trend" refers to a'. The model uses volatility equal to 0.30.

The actual return on investment will depend on the excess profits from relocation. To illustrate the impact of a difference in emission taxes in a more detailed way, figure 5a plots the excess profits as a function of total abatement costs as well as the total amount of emission taxes. All variables are calculated from the model presented above with b equal to 1.000[2], marginal production costs equal to 400 in both countries and d =500. The excess profits are measured against the profits from producing at home. Abatement costs and emission taxes are expressed in terms of total costs. From figure 5a it can be seen that at first, the impact of increased emission taxes on excess profits is more or less equal, i.e. if abatement costs and emission taxes are 5% of total costs, excess profits equal more or less the same percent of the profits from producing at home. Figure 5b plots the excess profits from relocation as a function of abatement costs and emission taxes expressed in terms of total revenue or output.

From both figures it is obvious that relocation will only be considered in those cases where emission taxes and abatement costs are very important. A number of authors have calculated the importance of environmental costs. Low (1992) for instance lists pollution abatement operating costs in 1988 USD as a percentage of industry output for

[2] A change this parameter will have impact the value of the investment project as $\frac{\partial V_3}{\partial b} = \frac{\frac{1}{2}\left(w + l\right)}{m - a'}$. An increase (decrease) of the size of the market will increase (decrease) the value of the investment project.

various SIC 3-digit industries and finds that the 3 highest ratio's equal 3,17% in the cement and hydraulic industry, 2,42% in the pulp mills industry and 2,39% in the wood buildings/mobile homes industry. Pollution abatement capital as a percentage of the total capital stock varies from country to country. In the USA (again 3 highest ratio's) for instance it equals 8,8% in basic metals, 7,2% in chemicals and 4,3% in paper products (Bouman, M. (1998)). Although these estimates are far from conclusive and we should keep in mind that the reference market in our model is a monopoly, they do suggest that the ranges used in figures 5a and 5b contain most, if not all, possibilities for various industries.

The evidence based on the model presented here and shown in figures 5a and 5b seems to suggest that the possibility of relocation for average industries is small. If abatement costs and emission taxes equal 10% expressed in terms of total costs, or 6% expressed in terms of output, then excess profits from relocation equal 11,5% of total profits from production at home. Returning to figure 4, this suggests that in the absence of any trend in the difference in emission taxes and in the case of zero volatility, relocation costs should not exceed a level that equals twice the profits from production at home as $\frac{p_e}{p_h} = 11{,}5\%$ and $\frac{p_e}{R} > 5\%$.

If the trend in the difference between emission taxes is positive, it has been shown in equation (32) that the conclusion does not change. If the trend in the difference between emission taxes is negative, the likelihood of relocation diminishes, as the 'discount' rate that is used is higher than the risk free rate. If uncertainty is added, the relocation threshold value for the total relocation cost is further diminished and the likelihood of relocation is further reduced.

Figure 5a: Excess profits from relocation as a function of abatement costs and emission taxes as a percentage of total costs (no foreign environmental policy)

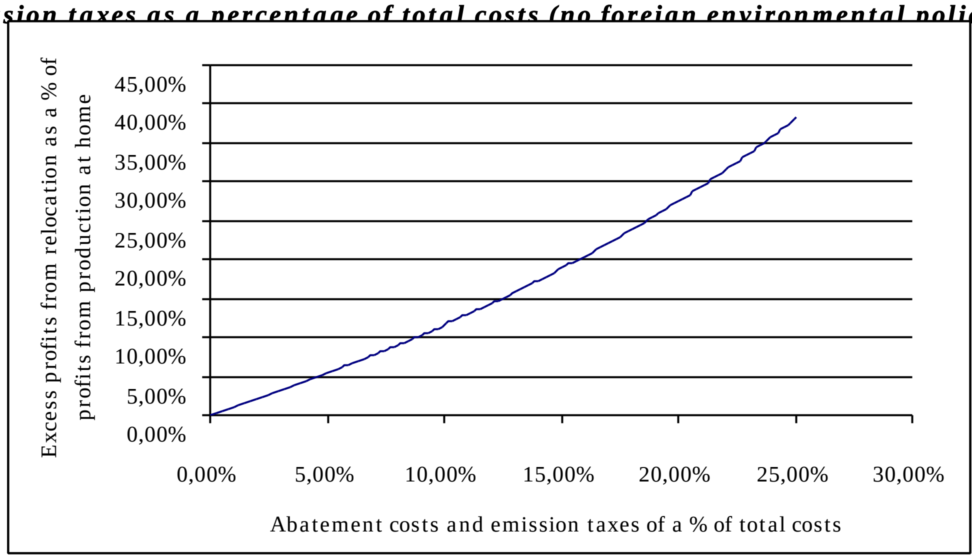
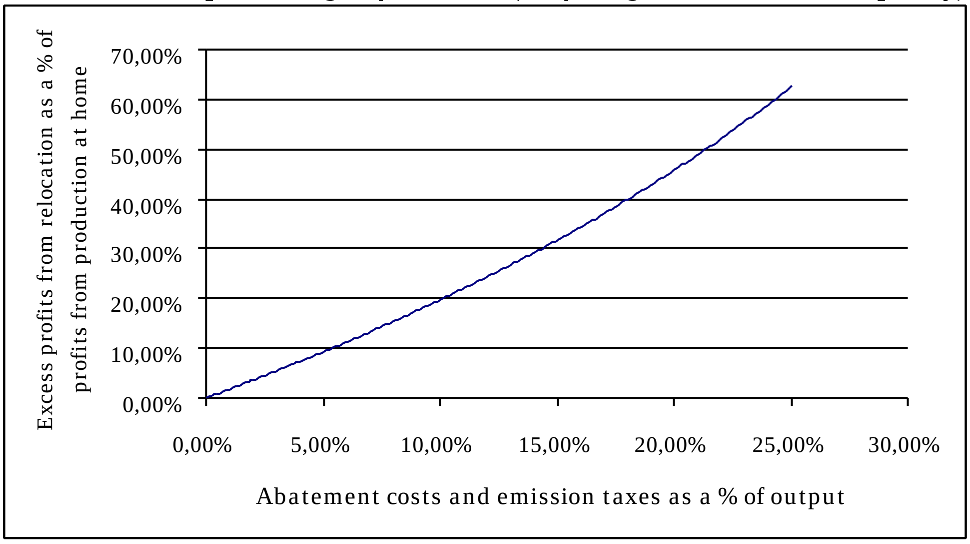


Figure 5b: Excess profits from relocation as a function of abatement costs and emission taxes as a percentage of revenue (no foreign environmental policy)

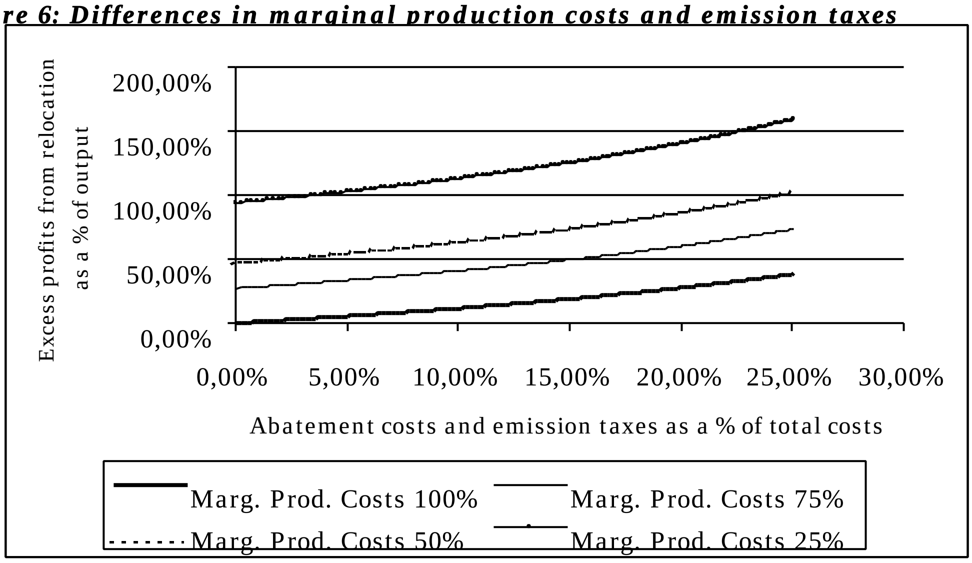


As was illustrated in figure 1, lower marginal production costs in the foreign country increase the excess profits from relocation. The difference in marginal production costs are 'net', i.e. they take into account both lower labour costs as well as the inconvenience of having to produce at a location which can be far removed from the actual market. There is some evidence that suggests that the difference in net marginal production costs might not always be very important. Labour costs for instance, could be a very important determinant of the difference in marginal production costs in labour intensive industries producing goods that can be shipped to the home market at low costs in industries that are characterised by the absence of major barriers to trade (Sleuwaegen et. al. (2000)). A survey by A.T. Kearney (2001) also suggests that both political and economic stability are other important elements that might increase costs. Furthermore, for some industries, there could be some location advantages in the home market. All of these suggest that, at least for some firms, the difference in marginal production costs might not be very important. The existence of a difference in marginal production costs might however be a reason why some firms choose to relocate, even in the absence of any difference in environmental compliance costs. As shown in figure 6, differences in marginal production costs could add significantly to the relocation probability. In figure 6, four different assumptions are made with respect to the difference in marginal production costs. Marginal production costs abroad equal 100%, 75%, 50% and 25% of those at home. In each of these cases, the abatement costs are expressed as a percentage of total costs. The excess profits from relocation are expressed as a percent of profits from production at home. The model used in this paper implies that a 25% difference in marginal production costs (i.e. c_f = 300; c_h = 400 and all other variables as above) results in excess profits from relocation in excess of 20% of the profits from production at home. Increasing the difference in marginal production costs increases the likelihood of relocation.

Note that the difference in marginal production costs might be negative, i.e. production costs at home are lower than production costs in the foreign country. This could be due to the existence of advantages of producing at home or agglomeration effects or large barriers to international trade. If that is the case, relocation is only likely in the presence of extreme large differences in environmental policy stringency.

Figures 5a, 5b and 6 clearly suggest that relocation due to differences in the stringency of environmental policies is unlikely. The model presented here clearly suggests that if relocation occurs, it is likely to be an exception and confined to few polluting industries. The survey results reported in Sleuwaegen et. al. (2000) support this overall conclusion. Their survey suggests that lower production costs could induce relocation. None of the respondents however mentioned environmental compliance costs as the major reason for relocation.

Figure 6: Differences in marginal production costs and emission taxes



Keller and Levinson (1999) have shown that differences in environmental policy stringency do not have a deterrent effect on the location of foreign direct investment. Combining those results with ours seems to suggest that environmental policy stringency does not have a major effect on the location of economic activity. Both relocation of existing firms and the location of new firms do not seem to be sensitive to differences in environmental stringency.

Ulph and Valentini (1997) have shown that environmental policy might have a 'hysteresis component'. The model presented here also exhibits hysteresis. To see this note that the firm, once the relocation decision is taken, will not return to its home country unless the difference in environmental stringency is reduced in a way that is much larger than the increase that lead to relocation in the first place. We will have to assume that there might be some advantages to production at home. Once the equilibrium shifts from production at home to production in the foreign country, the home country will have to lower emission taxes beyond the levels seen prior to relocation.

7. Summary and conclusion

The empirical evidence seems to suggest that environmental compliance costs do not cause relocation. If relocation occurs, other costs seem to be a major cause. The model that we presented in this paper explains these findings in two ways. First of all, when uncertainty is added to the decision-making process of a firm looking at the possibility to relocate, we find that the required return on investment can be substantial. This is especially the case if the firm expects the difference in environmental stringency to exhibit a negative trend. Secondly, excess profits from relocation because of environmental reasons seem to be small and will not be able to guarantee the required return in the presence of substantial relocation costs. The example that was used in the discussion indicated that for relocation costs in excess of twice the profits from production at home, relocation would not be profitable. Relocation because of environmental policy reasons seems to be confined to those cases where the differences in emission taxes are large, environmental policy at home is very stringent and there is little evidence that questions the sustainability of such a large difference.
The model does however predict relocation in the presence of differences in marginal production costs. It was shown that differences in marginal production costs can increase the likelihood of relocation.

The evidence presented here as well as in, for instance Keller and Levinson (1999), seems to offer environmental policy makers some degrees of freedom. The model seems to suggest that relocation fears due to environmental policy should not be exaggerated. Environmental policy can target a high level of environmental quality. It also suggests that it could be worthwhile to actively pursue international environmental policy initiatives. The model should not be used to conclude with respect to new investments. This can only be done if they involve both higher investment costs as well as positive excess profits in the foreign location.

The model can be extended in a number of ways. First of all the relocation costs could be made uncertain. Although this is a straightforward exercise, we have chosen to limit the analysis to the case where only excess profits are uncertain, as it is highly unlikely that this would alter the conclusions. Secondly, the difference in marginal production costs could be made uncertain. Again, given the evidence presented so far, it is highly unlikely that the conclusions of the model would change in a major way. Thirdly, it could be worthwhile to add the possibility of flexible instruments that allow a company to reduce emissions abroad but to use them as abatement at home. Most probably the results of this exercise would show that the probability of relocation is further reduced. The introduction of foreign competition on the domestic market could increase the probability of relocation.

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Appendix

Let's start from (3):

$$p_h^*(t) = q_h^{*2}(t) + t_h(t)\,a_h(t) - \frac{1}{2}\,d\,a_h(t)^2 \qquad \textbf{(A1)}$$

and note from (2) that the volume equals

$$q_h^*(t) = \frac{1}{2}\left(b - c_h^p - t_h(t)\right) \qquad \textbf{(A2)}$$

which, using the assumption that $c_h^p = c_f^p + w$ and $t_h(t) = t_f(t) + l$, and removing the time indicator and asterisks for ease of writing, can be written as $q_h = \frac{1}{2}\left(b - c_f^p - w - t_f - l\right)$. Rearranging yields

$$q_h = \frac{1}{2}\left(b - c_f^p\right) - \frac{1}{2}\left(w + t_f + l\right) = \tilde{q}_f - \frac{1}{2}\left(w + t_f + l\right) \qquad \textbf{(A3)}$$

i.e. the quantity produced at home equals the quantity produced in the foreign country in the absence of environmental policy minus an adjustment to take into account the difference in marginal costs and the existence of an emissions tax.

Substituting (A3) into (A1) yields

$$p_h = \tilde{q}_f^2 - \tilde{q}_f\left(w + t_h\right) + \frac{1}{4}\left(w^2 + 2wt_h + t_h^2\right) + t_h a_h - \frac{1}{2} d\,a_h^2 \qquad \textbf{(A4).}$$

From (2') we know that $\tilde{q}_f = q_f + \frac{1}{2}t_f$ so that (A4) can be written as

$$p_h = \tilde{q}_f^2 - \tilde{q}_f w - q_f t_h - \frac{1}{2}t_f t_h + \frac{1}{4}w^2 + \frac{1}{2}wt_h + \frac{1}{4}t_h^2 + t_h a_h - \frac{1}{2}d\,a_h^2 \qquad \textbf{(A5).}$$

In the absence of environmental policy, the profit function of production in the home country can be written in terms of the profit function in the foreign country. Given that the optimal quantity in the home country $\tilde{q}_h = \frac{1}{2}\left(b - c_f^p\right) - \frac{1}{2}w = \tilde{q}_f - \frac{1}{2}w$, the profit function in the absence of environmental policy can be written as

$$\tilde{p}_h = \tilde{p}_f - \tilde{q}_f w + \frac{1}{4}w^2 \qquad \textbf{(A6).}$$

With (A6), (A5) can be written as

$$p_h = \tilde{p}_h - \left(q_f - a_h\right)t_h - \frac{1}{2}t_f t_h + \frac{1}{2}wt_h + \frac{1}{4}t_h^2 - \frac{1}{2}d\,a_h^2 \qquad \textbf{(A5').}$$

Using $q_h = \frac{1}{2}\left(b - c_f^p - t_f\right) - \frac{1}{2}\left(w + l\right) = q_f - \frac{1}{2}\left(w + l\right)$ in the second term on the right hand side of (A5') and $t_f = t_h - l$ in the third term on the right hand side and collecting terms, (A5') becomes

$$p_h = \tilde{p}_h - \left(q_h - a_h\right) t_h - \frac{1}{2} d\, a_h^2 - \frac{1}{4} t_h^2 \qquad \textbf{(A7)}$$

Which is equal to (3') in the main body of the text.

Because we are mainly interested in the impact on the difference in profits between the home and foreign production case, we will modify (A7) in a way that allows us to see that difference right away. In order to do so, we will use the fact that $q_h = q_f - \frac{1}{2}\left(w + l\right)$, that $t_h = t_f + l$ and that a profit maximizing firm will set marginal abatement costs equal to the emission tax level:

$$\left.\begin{matrix} t_h = d\, a_h \\ \\ t_f = d\, a_f \end{matrix}\right\} \Rightarrow d\, a_h = d\, a_f + l \Rightarrow a_h = a_f + \frac{l}{d} \qquad \textbf{(A8)}$$

In terms of (A7) this yields:

$$p_h = \tilde{p}_h - \left(q_f - a_f\right)\left(t_f + l\right) + \frac{1}{2}\left(w + l\right)\left(t_f + l\right) + \left(\frac{l}{d}\right)\left(t_f + l\right) - \frac{1}{2} d\, a_h^2 - \frac{1}{4} t_h^2 \qquad \textbf{(A9).}$$

From (A8) it can be seen that the fifth term on the right hand side in (A9) $-\frac{1}{2} d\, a_h^2$ equals $-\frac{1}{2} d\left(a_f + \frac{l}{d}\right)^2 = -\frac{1}{2} d\, a_f^2 - l\, a_f - \frac{1}{2}\frac{l^2}{d}$ and that we can write the last term on the right hand side of (A9) $\frac{1}{4} t_h^2$ as $\frac{1}{4}\left(t_f + l\right)^2 = \frac{1}{4}\left(t_f^2 + 2 t_f l + l^2\right)$. In order to simplify (A9) further, we use the fact that $\tilde{p}_h = \tilde{p}_f - \tilde{q}_f w + \frac{1}{4} w^2$ and that $\tilde{q}_f = q_f + \frac{1}{2} t_f$. Substituting these in (A9) and rearranging a bit, we have

$$\begin{aligned} p_h = {} & \tilde{p}_f - \left(q_f - a_f\right) t_f - \frac{1}{2} d\, a_f^2 - \frac{1}{4} t_f^2 - \left(q_f + \frac{1}{2} t_f\right) w + \frac{1}{4} w^2 - \left(q_f - a_f\right) l \\ & + \frac{1}{2}\left(w + l\right) t_f + \frac{1}{2}\left(w + l\right) l + \left(t_f + l\right)\left(\frac{l}{d}\right) - \frac{1}{2} t_f l - \frac{1}{4} l^2 - a_f l - \frac{1}{2}\frac{l^2}{d} \end{aligned} \qquad \textbf{(A10).}$$

From equation (3) in the main body of the text we know that $p_f = \tilde{p}_f - \left(q_f - a_f\right) t_f - \frac{1}{2} d\, a_f^2 - \frac{1}{4} t_f^2$ so (A10) can be further reduced to

$$p_h = p_f - q_f\left(w + l\right) + \frac{1}{4}\left(w^2 + l^2\right) + \frac{1}{2} w l + \frac{l}{d}\left(t_f + \frac{1}{2} l\right) \qquad \textbf{(A11).}$$

The difference between the profits when the firm produces at the foreign location and the profits when production is located at home can easily been seen from (A11). The difference equals

$$p_f - p_h = p_e = q_f(w + l) - \frac{1}{4}\left(w^2 + l^2\right) - \frac{1}{2}w\,l - \frac{l}{d}\left(t_f + \frac{1}{2}l\right) \qquad \textbf{(A12).}$$

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