UNIVERSITEIT
GENT

**FACULTEIT ECONOMIE
EN BEDRIJFSKUNDE**

**HOVENIERSBERG 24
B-9000 GENT
Tel. : 32 - (0)9 – 264.34.61
Fax. : 32 - (0)9 – 264.35.92**

WORKING PAPER

Environmental policy uncertainty, policy coordination and relocation decisions

Tom Verbeke [1]

Marc De Clercq [2]

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[1] Center for Environmental Economics and Environmental Management (CEEM), Department of Economics, Ghent University (corresponding author: Hoveniersberg 24, 9000 Ghent, Belgium, tel. ++32 9 264 35 03, fax ++32 9 264 35 99, email: tom.verbeke@ugent.be

[2] Center for Environmental Economics and Environmental Management (CEEM), Department of Economics, Ghent University

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ABSTRACT

ENVIRONMENTAL POLICY UNCERTAINTY, POLICY COORDINATION AND RELOCATION DECISIONS

We analyse the relocation decision of a firm who is producing in one country (home country) but has the opportunity to relocate. The firm is faced with uncertain environmental policy formation both at home as well as in the foreign country. We allow for international environmental policy coordination and for environmental policy risks to be correlated with economy-wide risk. We show that the impact of uncertainty on the relocation decision depends on the absolute level of uncertainty. However, this relationship is substantially affected by the existence of policy coordination and the correlation between environmental policy uncertainty and economy-wide risks. In the case of coordinated environmental policies for instance, an U-shaped relation between uncertainty and relocation emerges.

KEYWORDS:

Location decision, policy uncertainty, environmental policy coordination, option value

JEL:

F18; Q28; D21

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 ([2], [16], [7], [18]).

We model the relocation decision as a choice between production in the home country and production in the foreign country. As in Motta and Thisse [10] our firm is located in the home country and faces a sunk relocation cost. Following Xepapadeas [21] we introduce uncertainty and assume that the changes in environmental policy stringency are uncertain. However, we do not restrict uncertainty to the home country. We explicitly take into account uncertainty abroad. Furthermore, we introduce a measure of explicit or implicit policy coordination. Thirdly, we allow for environmental policy risks to be correlated with economy-wide risks. We do not allow regulatory competition as we focus on the location decision of the firm. All variables used in the model are assumed to be known to or, with respect to uncertainty for instance, perceived by the firm.

This paper adds to the existing theoretical literature by revealing that environmental policy coordination and the correlation between environmental and economy-wide risks play a crucial role in the relocation behaviour of firms. Furthermore, environmental policy uncertainty abroad should be taken into account as well. Our model suggests that the empirical results may suffer from a missing variable bias related to the uncertainties with respect to environmental policy stringency, the international policy coordination and the way in which environmental policy risks correlate with economy-wide risk. The fact that panel data techniques seem to produce more evidence in favour of relocation due to environmental reasons suggests that some effects that are caught by the panel's country specific effects play an important role as control variable. This paper argues that uncertainty could be one of those effects that are caught by panel estimates but are lost in single time series or cross-section estimates. However, environmental policy uncertainty in one country is not sufficient. Our model clearly reveals a role for uncertainty in the foreign country and international policy coordination. Most empirical work has neglected these variables.

The remainder of the paper is organized as follows: the second paragraph of this paper reviews some of the relevant literature. The next paragraph presents the model. The fourth discusses the most important model results. The final section concludes.

2. Some relevant literature

Theoretical literature that deals with localisation decisions includes, among others, Motta and Thisse [10], Markusen [9], Ulph [17], Ulph and Valentini [19], Petrakis and Xepapadeas [12] and Xepapadeas [21]. Only the latter includes uncertainty with respect to policy stringency explicitly in his model.

Motta and Thisse [10] assume a two-country economy with two firms producing a homogeneous good and each of them located in one of the countries. They analyse the impact of a change in environmental policy in one of the two countries on the location decision of local firms. They assume location independent variable production costs and fixed relocation costs. In their model, relocation depends on the size of the market. If markets are small, relocation is never profitable and a more stringent environmental policy 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 [9] models the location decision by imperfectly competitive firms in the presence of trade barriers when confronted with environmental regulation. He shows that intra-firm reallocations within multinational firms are less sensitive to increased marginal costs compared to national firms. His analysis also points to the fact that the nature of the cost increases due to environmental policy plays a role in location decisions. 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 [19] use a two-country framework with one upstream and one downstream industry and two firms in each industry. Economic geography suggests 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 however, two equilibriums emerge but firms do not relocate. If environmental taxes increase further, firms relocate. 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.

None of these papers include environmental policy uncertainty. Petrakis and Xepapadeas [12] analyse the relocation decision of a monopolist depending on whether the government can commit herself to an emission tax before the relocation decision is taken or not. They show that if the government can do so, relocation is less likely. Commitment can be seen as a way to reduce environmental policy uncertainty in the home country. Xepapadeas [21] focuses on 1 firm and introduces environmental policy uncertainty in the home country. 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. Both these papers include environmental policy uncertainty but do so only from the perspective of the home country.

Concluding, theoretical literature suggests that relocation is possible and has identified various channels through which environmental policy affects relocation decisions. Although there is some support for environmental factors to have an effect on the location decision, Jeppesen and Folmer [4] argue that the impacts of environmental policy on location behaviour are insignificant or negligible. Sleuwaegen et al. [15] questioned companies on their motive to relocate. Their results suggest that environmental compliance costs are not an issue as none of their respondents mentioned them as an important reason for relocation. List et al. [6] analyse the relocation behaviour of plants in 62 counties in New York State from 1980 to 1990. They investigate whether the 'in-attainment" (IA) or 'out-of-attainment' (OA) designation under the US 1997 Clean Air Act Amendments had an impact on the relocation behaviour of plants. Firms moving into an OA area are subject to an environmental standard that requires them to use equipment that achieves the 'Lowest Achievable Emissions Rate' irrespective of the costs. Firms moving into IA counties on the other hand are subject to less stringent environmental standards. Their evidence clearly suggests that more stringent environmental regulations play a critical role in the location decision of relocating plants.

The empirical literature further suggests that the choice of the methodology might have an impact on the result. Jeppesen, List and Folmer [5] for instance argue that the type of model and estimation technique used to estimate new plant location decisions has an impact on the estimate of the effect of environmental stringency. Their evidence suggests that panel data estimates for instance yield larger evidence in support of the pollution haven hypothesis. List et al. [6] report that controlling for county-specific unobservables raises the costs of being an OA county. They argue that in their case, this might be due to the fact that counties that are or anticipate of becoming an OA introduce subsidies to compensate plants for additional costs.

3. The model

3.1. Basic set-up of the model

Following Xepapadeas [21] we focus on the behaviour of a small, risk-neutral firm within an industry with n identical firms. Our representative firm is producing at home (h) but has the possibility to relocate to a foreign (f) country to serve the competitive world market from that location. All variables will be denoted with a subscript h if they refer to variables assuming production at home and a subscript f to denote variables assuming production in the foreign country. A subscript i will be used if the location is not specified. The firm's production function is location independent and is of the form

$$q_i = Ze_i^{\varphi} \tag{1}$$

with q_i the level of production, e_i the environmental input, $\varphi \in]0,1[$ the elasticity of production with respect to the environmental input and Z a technology factor.

Notwithstanding the location-independent production technology, output may vary across countries due to differences in the level of environmental inputs. This is in line with Motta and Thisse [10] who assume location independent variable production costs. Furthermore equality with respect to production technologies allows us to focus on the role of the uncertainty with respect to future levels of environmental policy stringency and its effect on location decisions.

The firm receives a fixed exogenous world market price $\overline{p}$ per unit of production sold. Transport costs are assumed zero and environmental inputs are taxed at a rate τ_i. Environmental taxes should be interpreted broadly as each environmental policy instrument can be converted into a tax equivalent. Furthermore, the variable τ_i captures all costs associated with all environmental inputs and could be seen as a measure of environmental stringency. Throughout this paper we will assume that $\tau_i > 0$ and that the tax rate is not prohibitive. This assumption with respect to environmental policy stringency is in line with data for most sectors. Low [8], for instance, lists pollution abatement operating costs in 1988 USD as a percentage of industry output for 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 while the 3 lowest ratio's equal 0,01% (miscellaneous industries), 0,02% (search/navigation equipment and periodicals) and 0,04% (office & computing machines). Even for the lowest of the ratio's, total pollution abatement costs equalled 1988 USD 1,1 million.

We will assume that we can model the firm's perception of environmental policy stringency levels in both countries as correlated geometric Brownian motions

$$d\tau_h = \alpha_h \tau_h dt + \sigma_h \tau_h dz_h^{\tau} \tag{2}$$

$$d\tau_f = \alpha_f \tau_f dt + \sigma_f \tau_f dz_f^{\tau} \tag{3}$$

with $\alpha_i \tau_i$ the instantaneous drift rate, $(\sigma_i \tau_i)^2$ the instantaneous variance rate and $dz_i^\tau = \xi_i^\tau \sqrt{dt}$ the increment of a Wiener process with $\mathrm{E}[dz_f^\tau \, dz_h^\tau] = \rho_{fh} dt$, $\xi_i^\tau \overset{iid}{\rightarrow} (0,1)$ and ρ_{fh} the correlation coefficient.

From (2) and (3), it can be seen that the firm expects that environmental taxes will change over time at a rate of α_i in country *i*. However, it is unable to predict future stringency levels with certainty. The firm does not have perfect foresight with respect to, for instance, the exact timing of new environmental policy legislation, the instruments that will be used, the environmental inputs that will be targeted or the way in or the intensity of monitoring compliance. The instantaneous variance rate reflects the level of uncertainty surrounding future environmental policy stringency.

If we assume for instance that initial taxes are such that $\tau_h > \tau_f$, (2) and (3) imply that this does not need to be the case forever. Indeed, if $\alpha_h < \alpha_f$ environmental taxes in *f* are expected to catch up with those in *h* at some future date. Should $\alpha_h > \alpha_f$ the gap between emission taxes in *f* and *h* is expected to widen. The correlation coefficient $\rho_{fh} = \mathrm{E}\left[\xi_f^\tau \, \xi_h^\tau\right]$ can be seen as a measure perceived implicit or explicit policy coordination as it points to a shared component in the Wiener processes associated with the change in environmental policy stringency. If the firm believes that environmental policy is somehow coordinated, $0 < \rho_{fh} \leq 1$. We will refer to this case as coordinated environmental policies. On the other hand, if it believes that environmental policies are uncoordinated, it will assume that $-1 \leq \rho_{fh} \leq 0$. We will refer to this case as uncoordinated policies.

The optimum profit function equals ([20])

$$\pi_i\left(\tau_i, \varphi, Z, \overline{p}\right) = \left(\frac{1-\varphi}{\varphi}\right)\left(\frac{1}{\varphi \overline{p} Z}\right)^{\frac{1}{\varphi-1}} \tau_i^{\frac{\varphi}{\varphi-1}} \qquad (4).$$

From (4) it follows that

$$\frac{\partial \pi_i\left(\tau_i, \varphi, Z, \overline{p}\right)}{\partial \tau_i} < 0 \tag{5}$$

$$\frac{\partial^2 \pi_i\left(\tau_i, \varphi, Z, \overline{p}\right)}{\partial {\tau_i}^2} > 0 \tag{6}$$

By Ito's lemma ([11]) and noting that $\frac{\partial \pi_i}{\partial \tau_i}\tau_i = \pi_i \frac{\varphi}{\varphi - 1}$ with $\frac{\varphi}{\varphi - 1}$ the elasticity of the profit function with respect to a change in taxes and that $\frac{\partial^2 \pi_i}{\partial \tau_i^2}\tau_i^2 = \frac{\varphi}{(\varphi - 1)^2}$ with $\frac{1}{\varphi - 1} < 0$ the elasticity of the first derivative of the profit function with respect to the tax, it follows that

$$d\pi_i = \theta_i \pi_i dt + \gamma_i \pi_i dz_i^{\pi} \tag{7}$$

with $\theta_i = \frac{\varphi}{\varphi - 1}\left(\alpha_i + \frac{1}{2}\frac{\sigma_i^2}{\varphi - 1}\right)$, $\gamma_i = \sigma_i \frac{\varphi}{1 - \varphi}$, $dz_i^{\pi} = \zeta_i^{\pi}\sqrt{dt}$, $\zeta_i^{\pi} = -\xi_i^{\tau}$, $\mathrm{E}\left[dz_i^{\tau}\, dz_i^{\pi}\right] = -1dt$ and $\mathrm{E}\left[dz_f^{\pi}\, dz_h^{\pi}\right] = \rho_{fh} dt$. Equation (7) implies that the profits from producing in i are expected to change at a rate equal to θ_i. Just like future environmental stringency levels, profit flows are uncertain. The expected drift will be non-positive if $\alpha_i \geq \alpha_i^{\theta = 0} = \frac{1}{2}\frac{\sigma_i^2}{(1 - \varphi)}$ and will be larger in absolute value as φ increases. If $\alpha_i < \alpha_i^{\theta = 0}$ it will be the case that $\theta_i > 0$ and its value will increase with φ. If $\varphi < \frac{2\alpha_i}{\sigma_i^2 + 2\alpha_i}$ the expected drift in the profit function will be smaller than the expected drift in environmental policy stringency. The uncertainty of future profits, will rise with φ as well. Furthermore, $\gamma_i < \sigma_i$ for values of $\varphi < 1/2$.

With respect to dz_i^{π}, a positive shock in the tax rate implies a negative shock to the profit function due to the fact that $\frac{\varphi}{\varphi - 1} < 0$. A positive value for ξ_i^{τ} implies a negative value for ζ_i^{π} of the same magnitude, i.e. for any two realisations of the stochastic process we have that $\zeta_i^{\pi} = -\xi_i^{\tau}$ as the source of the uncertainty is the same for both the tax rate and the profit function. We will refer to ζ_i^{π} as environmental policy risk and write $\zeta_i^{\pi} = -\xi_i^{T}$ with $\gamma_i = \sigma_i \dfrac{\varphi}{1-\varphi}$ because it stresses the fact that positive environmental stringency shocks imply negative shocks for profits.

3.2. The relocation decision

When the firm relocates to *f* at time *t* it must abandon its production facilities in *h*. The value of these facilities equals

$$V_h\left(\pi_h\right) = \mathrm{E}_t\left[\int_0^{\infty} \pi_h\, e^{-(\mu_h - \theta_h)t}\right] dt = \frac{\pi_h}{\mu_h - \theta_h} \tag{8}$$

with

$$\mu_h = r + \rho_{s\pi_h} \phi \gamma_h \qquad (9),$$

$$\mu_h - \theta_h = \delta_h > 0 \qquad (10),$$

$\rho_{s\pi_h} = \mathrm{E}[\zeta_h^{\pi}\zeta_{sh}]$ the correlation between environmental risk and the Wiener process associated with the market portfolio in *h*, ϕ the market price of risk, *r* the risk free interest rate and δ_h the dividend yield (i.e. the difference between the risk-adjusted expected return and the profit growth rate). We will assume that the dividend yield is always positive. From the Capital Asset Pricing Model (CAPM), we know that $\mu_h > 0$. It follows that if $\mu_h > \theta_h$ then δ_h will be positive. This condition will always be satisfied if $\alpha_h \geq \alpha_h^{\theta=0}$. However, if $\alpha_h < \alpha_h^{\theta=0}$ then we have to assume that $\alpha_h > \alpha_h^{\min} = \alpha_h^{\theta=0} - \left(\dfrac{1-\varphi}{\varphi}\mu_h\right)$.

The Wiener process associated with the market portfolio, ζ_{sh}, can be seen as a measure of economy-wide risk in *h*. It follows that $\rho_{s\pi_h}$ can be seen as a measure of the correlation between the economy-wide and environmental policy risk. If the firm believes that environmental policy stringency and the economy-wide uncertainties are positively correlated, it would expect a negative correlation between the market portfolio and the change in profits and vice versa. We will say that economy-wide and environmental policy risks are negatively correlated if $-1 \leq \rho_{s\pi_h} \leq 0$ and positively correlated if $0 < \rho_{s\pi_h} \leq 1$.

In deciding whether to relocate or not, the firm has to compare its net present value when it produces in h with its value when it produces in *f*. The expected value at time t of the discounted profits in *f* equals

$$V_f\left(\pi_f\right)=\mathrm{E}_t\left[\int_0^{\infty} \pi_f\, e^{-(\mu_f-\theta_f)t} dt\right]=\frac{\pi_f}{\mu_f-\theta_f} \tag{11}$$

with

$$\mu_f = r + \rho_{s\pi_f}\phi\gamma_f \tag{12}$$

$$\mu_f - \theta_f = \delta_f > 0 \tag{13}$$

with $\rho_{s\pi_f} = \mathrm{E}[\zeta_h^{\pi}\zeta_{sf}]$ and ζ_{sf} a measure of economy-wide risk in *f*. We can write $\mu_f - \theta_f = \delta_f$ as the opportunity cost of delaying relocation in π_f. If the firm were to relocate now, it would expect a return equal to μ_f. If the firm does not relocate, the expected profits change at a rate equal to θ_f. The difference between these two rates equals the return that the firm did not earn because it decided not to relocate. Again in order for $\delta_f > 0$ we have to assume that $\alpha_f > \alpha_f^{\min} = \alpha_f^{\theta=0} - \left(\frac{1-\varphi}{\varphi}\mu_f\right)$.

If the firm relocates at time *t*, it will incur sunk costs. First of all, the firm needs to physically relocate or sell its production facilities in h to finance the investment in *f*. Physical relocation will involve costs associated with the transport and re-building of the production facilities in *f*, costs associated with the in-activity of the facilities, … . Selling production facilities involves sunk costs as well. From the real options literature[1] it is well known that the value of the investment should exceed the irreversible investment costs. As Pindyck [13] argues, most firm or industry specific investments are irreversible. He further argues that

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[1] for a review: [13], [1] and [14]

even investments that are not specific to a firm or an industry are partly irreversible. So if the firm sells its facilities in h as opposed to physical relocation, the investor buying them will require a discount on their value, even if these assets are not firm or industry specific. This discount can be seen as a measure of the firm or industry specificity of the assets the firm sells in h. Therefore a firm cannot expect to receive the full amount of the expected discounted value of its profits (equation (8)).

Secondly, if the investment in f turns out to be a 'bad' one, physical relocation back to h or the sale of production facilities in f and re-investing the proceeds in h will again involve irreversible costs. In order to keep our model simple, we will assume that sunk costs of physical relocation are the same as the sunk costs of the sale of assets in h and we will assume that they are equal to a fixed multiple m of the value of the firm in h. It follows that the sunk costs of relocation, R, equals

$$R = m\frac{\pi_h}{\delta_h} \tag{14}$$

with $m > 0$. From the definition of m, it follows that it will be higher if the firm or industry specificity of the assets held by the firm is large. If the firm incurs the sunk cost R it will receive assets in f worth $V_f\left(\pi_f\right)$. From (14), it can be seen that R depends on π_h. Due to the linearity of the dependency however, R will follow a geometric Brownian motion with the same instantaneous drift and variance as π_h, i.e.

$$dR = \theta_h R dt + \gamma_h R dz_h^{\pi} \qquad (15).$$

From the real options literature, it is well known that an option to postpone an investment involving sunk costs and uncertainty has value (Dixit and Pindyck [1]). Any relocation should thus compensate the investor both for the sunk costs and for 'giving up' the value of the option to postpone relocation. As shown in appendix 1, relocation requires that the profits from production in f are at least equal to a threshold level π_f^*:

$$\pi_f^* = \left(\frac{\beta_1}{\beta_1 - 1}\right)H \tag{16}$$

with $H = \delta_f \dfrac{m}{\delta_h}\pi_h$. If the profit from producing in *f* exceeds the threshold level π_f^* relocation will be immediate. As long as $\pi_f < \pi_f^*$ the firm will keep production in *h*. From (4) it follows that it is not sufficient that $\tau_f < \tau_h$. The firm requires that the difference in environmental policy stringency is large enough so as to make sure that the profit in *f* compensates both the sunk costs as well as the value of the relocation option.

3.3. Model results

With respect to the sunk relocation costs *R*, (16) confirms a well-known result from the real option literature: the relocation threshold level of profits in *f*, π_f^*, increases with m and π_h. Using (5) and (6) it can be seen that with $\tau_f < \tau_h$, an increase in τ_h and τ_f of equal magnitude increases the difference between the threshold level π_f^* and the actual profits π_f. Indeed, the impact of an increase in environmental policy stringency on profits in *h* will be smaller than the impact of the same increase on profits in *f*.

With respect to σ_h and σ_f, (16) suggests three channels through which they affect the relocation decision. This is the case because we cannot assume that the opportunity cost of delaying relocation is constant. Indeed, if the uncertainty changes, so does the risk-adjusted expected return. As all other variables affecting δ_i are fixed with respect to uncertainty, it has to adjust to preserve equilibrium (Dixit and Pindyck [1]). The first derivative of π_f^* with respect to σ_i,

$$\frac{\partial \pi_f^*}{\partial \sigma_i} = \frac{\partial \pi_f^*}{\partial \beta_1}\frac{\partial \beta_1}{\partial \sigma_i} + \frac{\partial \pi_f^*}{\partial \beta_1}\frac{\partial \beta_1}{\partial \delta_i}\frac{\partial \delta_i}{\partial \sigma_i} + \frac{\partial \pi_f^*}{\partial \delta_i}\frac{\partial \delta_i}{\partial \sigma_i} \tag{17}$$

shows that two channels pass through the options component $(\dfrac{\beta_1}{\beta_1 - 1})$ while the other passes through passes through δ_i.

As far as the first channel, $\frac{\partial \pi_f^*}{\partial \beta_1}\frac{\partial \beta_1}{\partial \sigma_i}$, is concerned, (16) shows that the higher the values of $\frac{\beta_1}{\beta_1 - 1}$, the higher π_f^* should be before the firm proceeds to relocation. With respect to the impact of uncertainty on β_1 the following proposition holds:

PROPOSITION 1: *For a given level of* δ_i, *an increase in* σ_i *lowers the value of* β_1 *if environmental policies are not coordinated or if* $\sigma_i > \sigma_j \rho_{fh}$ *with coordinated environmental policies while it increases the value of* β_1 *if* $\sigma_i < \sigma_j \rho_{fh}$ *with coordinated environmental policies. Furthermore, with coordinated environmental policies, it holds that if* $\frac{\partial \beta_1}{\partial \sigma_i} > 0$ *then* $\frac{\partial \beta_1}{\partial \sigma_j} < 0$. *An increase in* σ_i *will not change the value of* β_1 *if* $0 < \frac{\sigma_i}{\sigma_j} = \rho_{ij} \leq 1$.

PROOF: *see annex 2.*

It is well known from the option literature that uncertainty increases the value of an option ([3]). The option to relocate has two sources of uncertainty: the uncertainty associated with $d\pi_h$ and $d\pi_f$. If these flows are negatively correlated, then an increase in the uncertainty associated with one of these profit flows increases the overall uncertainty, which increases the value of the option to postpone relocation. If, on the other hand the two sources of uncertainty are correlated, the total variance of the portfolio will decrease if the smaller of the two uncertainties increases. This is due to the fact that the negative correlation effect on the covariance ($-2\gamma_f \rho_{fh}$) outweighs the positive impact on the variance ($2\gamma_h$) and hence, the total variance decreases.

Proposition 1 emphasizes the importance to take policy coordination into account. The level of perceived policy coordination has a profound impact on the way in which higher levels of uncertainty affect the options component of the optimal relocation rule. Indeed, if uncertainty in the home country is small relative to the foreign country and the firm believes that policy is coordinated, higher levels of uncertainty at home will reduce the threshold level of profits required in the foreign country before relocation is considered. If on the other hand relative levels of uncertainty in the foreign country are small relative to the level at home, higher levels of uncertainty will increase the threshold level of profits in the foreign country.

With respect to the second channel, $\frac{\partial \pi_f^*}{\partial \beta_1}\frac{\partial \beta_1}{\partial \delta_i}\frac{\partial \delta_i}{\partial \sigma_i}$, the following proposition holds:

PROPOSITION 2: *If economy-wide and environmental policy risks in i are negatively correlated or if* $\sigma_i > \phi\rho_{s\pi_i}(1-\varphi)$ *when they are positively correlated in i, then an increase in* σ_i *will increase* β_1 *through its influence on* δ_i *if i=h and reduce the value of* β_1 *through its influence on* δ_i *if i=f. If* $0 < \sigma_i < \phi\rho_{s\pi_i}(1-\varphi)$ *when economy-wide and environmental policy risks are positively correlated in i, an increase in* σ_i *will reduce* β_1 *through its influence on* δ_i *if i=h and will increase* β_1 *if i=f. If* $\sigma_i = \phi\rho_{s\pi_i}(1-\varphi)$ *then a change in* σ_i *will not influence* β_1*.*

PROOF: *see annex 3.*

The opportunity cost of the relocation project equals δ_f. If an increase in uncertainty reduces the opportunity cost of the relocation project, it reduces the opportunity cost of holding on to the option to relocate. This increases the option's value. If, on the other hand the opportunity cost rises, so does the cost of keeping the option, which reduces its value. With respect to δ_h the opposite happens. If an increase in uncertainty has a positive effect on the dividend yield δ_h, the opportunity cost of not holding on to production in h increases. This increases the value of this option.

PROPOSITION 3: *If economy-wide and environmental policy risks in i are negatively correlated or if* $\sigma_i > \phi\rho_{s\pi_i}(1-\varphi)$ *when they are positively correlated in i, then an increase in* σ_i *will increase* π_f^* *for a given level of* β_1 *if i=h and will reduce* π_f^* *for a given level of* β_1 *if i=f. If* $0 < \sigma_i < \phi\rho_{s\pi_i}(1-\varphi)$ *when economy-wide and environmental policy risks in i are* *positively correlated, an increase in* σ_i *will reduce* π_f^* *for a given level of* β_1 *if i=h and will increase* π_f^* *for a given level of* β_1 *if i=f. If* $\sigma_i = \phi\rho_{s\pi_i}(1-\varphi)$ *with* $0 < \rho_{s\pi_i} \leq 1$ *then a change in* σ_i *will not influence* π_f^* *for a given level of* β_1.

Proof: From $\partial\pi_f^* \big/ \partial\delta_h = -\frac{\beta_1}{\beta_1 - 1}\delta_f m \frac{\pi_h}{\delta_h^2} < 0$, $\partial\pi_f^* \big/ \partial\delta_f = \frac{\beta_1}{\beta_1 - 1} m \frac{\pi_h}{\delta_h} > 0$ and $\partial\delta_i \big/ \partial\sigma_i$ proposition 3 follows.

If an increase in uncertainty reduces the opportunity cost of the relocation project in *f*, it can be seen from (11) that this increases the value of the relocation project. It follows that relocation will occur at lower levels of profits in *f*. If an increase in uncertainty reduces the dividend yield in *h*, it increases the value of the firm in *h*. It follows that higher profits are needed in *f* before relocation is considered.

Propositions 2 and 3 emphasize the importance to take the perceived correlation between economy-wide and environmental policy risk into account. Indeed, if both risks are positively correlated, then an increase in environmental policy uncertainty has a negative effect on δ_i. However, in the opposite case when these risks are negatively correlated, higher uncertainty will have a positive effect on δ_i if uncertainty is low to modest while it will have a negative impact if uncertainty is high.

4. Discussion

Proposition 1 to 3 show that the various channels through which environmental policy uncertainty influences the relocation decision do not share the same sign. In order to investigate the overall impact of environmental policy uncertainty, policy coordination and correlation between economy-wide and environmental policy risk, we performed a number of simulations. Results are reported in table 1. The simulations are designed to analyse the behaviour of π_f^* as well as $\partial\pi_f^*/\partial\sigma_h$ for σ_h equal to 0.05, 0.15 and 0.25, ρ_{fh} equal to –0.75 (reported in panel A) and 0.75 (panel B), for $\rho_{s\pi_f}$ equal to –0.75 (panels A1 and B1) and 0.75 (panels A2 and B2) and $\rho_{s\pi_h}$ equal to –0.75, 0 and +0.75. To calculate the slope, $\partial\pi_f^*/\partial\sigma_h$, we measured the difference between π_f^* for $\sigma_h + 0.01$ and π_f^* for σ_h given all other variables. Table 2 reports the results of comparable simulations that were performed to measure the impact of changes in σ_f on π_f^* and $\partial\pi_f^*/\partial\sigma_f$.

[Insert table 1 about here]

[Insert table 2 about here]

Tables 1 and 2 clearly show that both the correlation between economy-wide and environmental policy risk as well as environmental policy coordination matters in assessing the impact of uncertainty on the relocation threshold level of profits in *f*. Comparing the level of π_f^* with $\rho_{fh} = -0.75$ (panel A) and $\rho_{fh} = 0.75$ (panel B) reveals that the former results in level of π_f^* that are always higher then those reported for the latter. This is due to the fact that higher levels of environmental policy coordination reduce the overall level of uncertainty. From the first derivative of (16) with respect to ρ_{fh}, it can be seen that higher levels of policy coordination lower the relocation threshold level of profits in *f*.

Including environmental policy coordination affects the shape of the relation between the relocation threshold and environmental policy uncertainty in *h* or *f*. Comparing panels A and B reveals that the slope is always less steep if environmental policies are coordinated compared to the situation where this is not the case. Furthermore, panel B shows that for low levels of environmental policy uncertainty the slope is actually negative if policies are coordinated. Notice from table 2 that these negative values for the slope are even visible at higher levels of environmental uncertainty in *f*. This suggests that the existence of international environmental policy coordination results in an U-shaped relation between the relocation threshold level of profits in *f* and environmental policy uncertainty in *h* or *f*. At first, an increase in environmental policy uncertainty reduces the relocation threshold. However, at some point, higher levels of uncertainty result in an increase of π_f^*. This U-shaped relation is due to proposition 1: the sign of $\partial\beta/\partial\sigma_i$ changes from positive (negative) when σ_i surpasses (falls below) $\sigma_j\rho_{fh}$.

For coordinated environmental policies, these results are in line with those obtained by Petrakis and Xepapadeas [12]. These authors find that the ability to pre-commit to an environmental tax level reduces the relocation threat. Our model would predict the same outcome. If governments pre-commit to an emission tax, one can argue that this reduces the level of environmental policy uncertainty. In the case of coordinated environmental policies, this increases the level of the relocation threshold and hence, reduces the relocation threat. For uncoordinated environmental policies on the other hand, the ability to pre-commit offers the government in *f* a way to attract investment.

With respect to the correlation between economy-wide and environmental policy risk, tables 1 and 2 show that it affects the relocation decision and the way in which uncertainty translates into the relocation threshold level of profits in *f*. Comparing panels A1 and A2 or B1 and B2 from table 1 reveals that, in the home country *h*, higher levels of $\rho_{s\pi_f}$ are associated with higher levels of both π_f^* as well as $\partial\pi_f^*/\partial\sigma_h$ while the opposite is true for $\rho_{s\pi_h}$. If economy-wide and environmental policy risks in *f* are correlated, the firm's profit flows from *f* will be more volatile compared to the case they are uncorrelated. This higher risk profile translates into higher levels of the expected return (see (12)). Although this increases the opportunity costs of not relocating (proposition 2), it also reduces the value of the relocation project (proposition 3). The latter effect outweighs the former and hence, the firm requires higher profits in *f* before it considers relocation. If economy-wide risk and environmental policy in *f* are not correlated, negative shocks to its profit due to shocks in the level of environmental policy stringency will be compensated in part by positive economy-wide shocks. This reduces the overall volatility of the firm's profit flows from *f* and hence the attractiveness of relocation. All other things being equal, the firm will relocate at lower levels of profits in *f*.

With respect to the correlation of economy-wide and environmental policy risks in h a similar line of reasoning helps to explain the results presented in the various columns in panels A1, A2, B1 and B2 from table 1. If these risks are uncorrelated, shocks to the profits due to changes in environmental policy stringency will be compensated by positive surprises due to economy-wide shocks. If the risks are correlated, negative shocks to the profits due to changes in environmental policy stringency will be enhanced by economy wide developments. Hence, in the case of uncorrelated risks, the predictability of future profits is better compared to the case of correlated risk and the firm requires a lower level of return (see (9)). Although this increased predictability lowers the dividend yield and hence the opportunity cost of relocation (proposition 2) it increases the value of the firm in h (proposition 3). It follows that the firm will require higher profits in *f* before it considers relocation if economy-wide and environmental policy risks in h are correlated compared to the situation where they are not.

The various panels of table 1 reveal that the sensitivity of π_f^* for changes in σ_h is higher if economy-wide and environmental policy risks in *f* are correlated. Comparing the slope for different levels of $\rho_{s\pi_h}$ shows that it is higher for uncorrelated risks in h. Higher levels of uncertainty increase the value of waiting. Furthermore, if economy-wide and environmental risks in h are uncorrelated, an increase in the level of environmental risk will reduce the required return in h, which increases the value of the production facilities in h. This adds to the effect of the increase in risk on the opportunity to wait. If, on the other hand, risks are correlated, the increase in environmental policy uncertainty increases the required return. As this reduces the value of the production facilities in h, it lowers the effect of the increased uncertainty on the opportunity to wait. These results can also be verified from table 2.

The results from this paper seem be corroborate the empirical estimates. List et al. [6] for instance attribute their finding that controlling for county-specific unobservables results in higher costs in terms of relocation of an AO-designation to the fact that AO counties might offer subsidies to firms to compensate them for additional environmental costs. Our model suggests another channel through which these subsidies have an impact on the relocation attractiveness of such a county. Subsidies could be seen as a way to make sure that environmental policy and economy-wide risks are uncorrelated. Indeed, a negative shock to profits due to environmental policy is (partly) compensated by financial flows from the government. Whether environmental policies over various countries are coordinated or not, the evidence presented in table 2 suggests that this lowers the relocation threshold and hence, increases the attractiveness for relocating firms.

Given the desire of most governments to keep production at home, the question is: "how does one convince a firm to keep producing at home?". If the firms believe that environmental policies are coordinated internationally, one way to convince them is to make sure that the policy path is very predictable and environmental policy and economy-wide risks are negatively correlated. This seems to favour pro-cyclical environmental policies. Although explicit international policy coordination is out of the realm of national decision-making, implicit coordination is not and all other variables are within the limits of policy making. Implicit or explicit policy coordination offers another 'advantage' for h: if policies are coordinated, it can be seen from table 2 (panel B) that *f* will have to increase environmental policy uncertainty in order to convince firms to relocate.

Not all industries are affected in the same way. As was shown, the investment cost seems to depend on the industry or firm specificity of the assets used to produce in *h*. Although these policy conclusions are not limited in terms of this specificity, the model suggests that the 'good environmental practices' are especially relevant for those industries where firm or industry specificity is less an issue.

5. Conclusion

This paper presents a model for a firm that has an option to relocate to another country where environmental policies are less stringent. Future environmental policy stances in both countries are uncertain. The results of this paper clearly suggest that uncertainty matters. However, it is not so that higher levels of environmental policy uncertainty always lower the probability that firms relocate. The model results indicate that it is important to take into account environmental policy coordination, the correlation between environmental policy shocks and economy-wide risk as well as the level of uncertainty in one country relative to the level in the other country.

The model presented in this paper suggests that regulatory competition does not need to be based on stringency levels. Indeed, if environmental policies are coordinated, governments can try to persuade firms to keep production at home through the level of environmental policy uncertainty and to make sure that environmental policy shocks are correlated with economy-wide risk.

In terms of empirics our model points to a possible missing variable bias in the literature. Empirical estimates of the impact of environmental policy stringency should include measures of environmental policy risk, international policy cooperation and the cyclical behaviour of environmental policies. To the extent that panel data methods allow capturing some of these variables through fixed effects, it is not surprising that panel data studies reveal more evidence in favour or relocation. However, even panel data methods should include at least a variable to control for the extent to which a country cooperates in environmental policy formation.

ANNEX 1: PROOF OF (16)

We will follow Dixit and Pindyck [1] and use the contingent claims approach to value the option to relocate, $F(\pi_f, R)$. In order to do so, we have to assume that we can find 2 assets that span the risks associated with π_f and R respectively. We will refer to these assets as π_f and R. Let us consider a portfolio with 1 unit of the option to relocate, z_f units short of π_f and z_h units short of R. The total value of this portfolio (W) equals

$$W = F(\pi_f, R) - z_f \pi_f - z_h R \tag{18.}$$

By Ito's lemma ([11]), the change in the value of this portfolio equals

$$\begin{aligned} dWdt = {} & \left(\frac{\partial F}{\partial \pi_f} - z_f \right) d\pi_f + \left(\frac{\partial F}{\partial R} - z_h \right) dR \\ & + \frac{1}{2} \left(\gamma_f^2 \pi_f^2 \frac{\partial^2 F}{\partial \pi_f^2} + \gamma_h^2 R^2 \frac{\partial^2 F}{\partial R^2} + 2 \gamma_f \gamma_h \rho_{fh} R \pi_f \frac{\partial^2 F}{\partial \pi_f \partial R} \right) dt \end{aligned} \tag{19}$$

To make this portfolio riskless, we can choose $z_f = \dfrac{\partial F}{\partial \pi_f}$ and $z_h = \dfrac{\partial F}{\partial R}$. A riskless portfolio should earn the risk free rate r. From (19), the total capital gain on the portfolio equals

$$\frac{1}{2} \left(\gamma_f^2 \pi_f^2 \frac{\partial^2 F}{\partial \pi_f^2} + \gamma_h^2 R^2 \frac{\partial^2 F}{\partial R^2} + 2 \gamma_f \gamma_h \rho_{fh} R \pi_f \frac{\partial^2 F}{\partial \pi_f \partial R} \right) dt \tag{20.}$$

However, the short position requires a payment equal to the dividend yield δ_i on each of the short positions. To hold on to the short position, a payment equal to $(\delta_h z_h R + \delta_f z_f \pi_f) dt$ will be needed in each period from t to $t+dt$. Subtracting these payments from the sure capital gain in (20) yields the guaranteed return on the portfolio W. Because this return is guaranteed, it equals the return on a riskless asset r. It follows that

$$rWdt = \left[\frac{1}{2} \left(\gamma_f^2 \pi_f^2 \frac{\partial^2 F}{\partial \pi_f^2} + \gamma_h^2 R^2 \frac{\partial^2 F}{\partial R^2} + 2 \gamma_f \gamma_h \rho_{fh} R \pi_f \frac{\partial^2 F}{\partial \pi_f \partial R} \right) - \left(\delta_f \pi_f \frac{\partial F}{\partial \pi_f} + \delta_h R \frac{\partial F}{\partial R} \right) \right] dt \tag{21}$$

Rearranging (21) and using (18) yields

$$\begin{aligned}&\frac{1}{2}\left(\gamma_f^2\pi_f^2\frac{\partial^2 F}{\partial \pi_f^2}+\gamma_h^2R^2\frac{\partial^2 F}{\partial R^2}+2\gamma_f\gamma_h\rho_{fh}R\pi_f\frac{\partial^2 F}{\partial\pi_f\partial R}\right)+\left[r-\delta_f\right]\pi_f\frac{\partial F}{\partial \pi_f}\\&+(r-\delta_h)R\frac{\partial F}{\partial R}-rF=0\end{aligned} \qquad (22).$$

This partial differential equation should be solved subject to the well-known value-matching condition (the value of production in f at the optimal relocation time minus the sunk relocation costs at the optimal relocation time should equal the value of the option at the optimal relocation time)

$$F\left(\pi_f^*,R^*\right)=\frac{\pi_f^*}{\delta_f}-R^* \qquad (23)$$

and smooth-pasting conditions:

$$\frac{\partial F\left(\pi_f^*,R^*\right)}{\partial R^*}=-1 \qquad (24)$$

$$\frac{\partial F\left(\pi_f^*,R^*\right)}{\partial \pi_f^*}=\frac{1}{\delta_f} \qquad (25).$$

We'll follow the approach used by [1] and define the ratio $w=\frac{\pi_f}{R}$. From (23) it can be seen that the value of the option should be homogeneous of degree 1. If we multiply both π_f and R with the same constant u, it can be seen from (23) that the value of the relocation project as well as of the option would be multiplied by that same constant u. By setting $u=\frac{1}{R}$ we can write the value of the option as $F\left(\pi_f,R\right)=RF\left(1,\frac{\pi_f}{R}\right)$. Using $w=\frac{\pi_f}{R}$ the value of the option becomes $RO(w)$. Substituting $RO(w)$ in (22), expanding the derivatives, multiplying all terms with $\frac{1}{R}$ and rearranging yields

$$\frac{1}{2}\left[\gamma_f^2+\gamma_h^2-2\gamma_f\gamma_h\rho_{fh}\right]w^2\frac{d^2O}{dw^2}+\left[\delta_h-\delta_f\right]w\frac{dO}{dw}-\delta_hO=0 \qquad (26).$$

Solving (26) for $O(w)$ and assuming a solution $O(w)=Aw^{\beta}$ yields a quadratic in β:

$$Q(\beta)=\frac{1}{2}\Gamma_1^2\beta^2+\Gamma_2\beta-\delta_h=0 \qquad (27)$$

with

$$\Gamma_1 = \sqrt{\gamma_h^2 + \gamma_f^2 - 2\gamma_h\gamma_f\rho_{fh}}$$

$$\Gamma_2 = \Delta - \frac{1}{2}\Gamma_1^2$$

$$\Delta = \delta_h - \delta_f$$

The variable Γ_1 can be interpreted as an uncertainty parameter while Δ reflects the difference between the dividend yield and the opportunity cost of delaying relocations. Equation (27) has two roots one of which is negative while the other is positive:

$$\beta_1 = \frac{1}{2} - \frac{\Delta}{\Gamma_1^2} + \sqrt{\left(\frac{\Delta}{\Gamma_1^2} - \left(\frac{1}{2}\right)\right)^2 + \frac{2\delta_h}{\Gamma_1^2}} > 1 \tag{28}$$

$$\beta_2 = \frac{1}{2} - \frac{\Delta}{\Gamma_1^2} - \sqrt{\left(\frac{\Delta}{\Gamma_1^2} - \left(\frac{1}{2}\right)\right)^2 + \frac{2\delta_h}{\Gamma_1^2}} < 0 \qquad (29).$$

The solution to equation (26) becomes $A_1 w^{\beta_1} + A_2 w^{\beta_2}$. However, because $\beta_2 < 0$, $A_1 w^{\beta_1} + A_2 w^{\beta_2}$ would approach infinity as $w \to 0$. Because the option can have no value if $\pi_f \to 0$ we have to set $A_2 = 0$.

Substituting the value of the option in the value matching condition for $O(w)$

$$O\left(w^*\right) = \frac{w^*}{\delta_f} - 1 \tag{30}$$

and the smooth-pasting conditions

$$O\left(w^*\right) - w^* \frac{dO}{dw^*} = -1 \tag{31}$$

$$\frac{dO}{dw^*} = \frac{1}{\delta_f} \tag{32}$$

yields

$$A_1 w^{*\beta_1} = \frac{w^*}{\delta_f} - 1 \tag{33}$$

and (using (32))

$$\beta_1 A_1 w^{*\beta_1 - 1} = \frac{1}{\delta_f} \qquad (34).$$

Dividing (33) by (34) and rearranging yields the optimal value of w

$$w^* = \left(\frac{\beta_1}{\beta_1 - 1}\right)\delta_f \qquad (35).$$

From (35) it follows that the firm will relocate if $w \geq w^*$ and keep producing in h for values of $w < w^*$. Using the definition of w the firm will relocate if

$$\frac{\pi_f}{R} \geq \left(\frac{\pi_f}{R}\right)^* = \left(\frac{\beta_1}{\beta_1 - 1}\right)\delta_f \qquad (36).$$

ANNEX 2: PROOF OF PROPOSITION 1

Totally differentiate (27) with respect to Γ_1

$$\frac{\partial Q(\beta)}{\partial \Gamma_1} + \frac{\partial Q(\beta)}{\partial \beta_1}\frac{\partial \beta_1}{\partial \Gamma_1} = 0 \qquad (37).$$

Because both $\frac{\partial Q(\beta)}{\partial \beta_1}$ and $\frac{\partial Q(\beta)}{\partial \Gamma_1}$ are positive at β_1 it follows that $\frac{\partial \beta_1}{\partial \Gamma_1} < 0$. With respect to Γ_1 we know that

$$\frac{\partial \Gamma_1}{\partial \gamma_h} = \frac{\left(\sigma_h - \sigma_f \rho_{fh}\right)}{\Gamma_1}\frac{\varphi}{1-\varphi} \qquad (38)$$

$$\frac{\partial \Gamma_1}{\partial \gamma_f} = \frac{\left(\sigma_f - \sigma_h \rho_{fh}\right)}{\Gamma_1}\frac{\varphi}{1-\varphi} \qquad (39).$$

From the definition of γ_i, it can be seen that $\frac{\partial \gamma_i}{\partial \sigma_i} = \frac{\varphi}{1-\varphi} > 0$.

If $-1 \leq \rho_{fh} \leq 0$ then it holds that $\frac{\partial \Gamma_1}{\partial \gamma_i} > 0$ and $\frac{\partial \beta_1}{\partial \sigma_i} < 0$.

If $0 < \rho_{fh} \leq 1$ then it will hold that $\frac{\partial \Gamma_1}{\partial \gamma_i} < 0$ if $\sigma_i < \rho_{fh}\sigma_j$. Let us assume that $\sigma_i - \sigma_j \rho_{ij} < 0$. It follows that $\sigma_i < \sigma_j$ so it must be that $\sigma_j - \sigma_i \rho_{ij} > 0$ and that

$\frac{\partial \Gamma_1}{\partial \gamma_i} = -\frac{\partial \Gamma_1}{\partial \gamma_j}$ with $\frac{\partial \Gamma_1}{\partial \gamma_i} > 0$ if $\sigma_i > \sigma_j$ and $\frac{\partial \Gamma_1}{\partial \gamma_i} < 0$ if $\sigma_i < \sigma_j$. If $\sigma_i > \sigma_j$ then it immediately follows that $\frac{\partial \beta_1}{\partial \sigma_i} < 0$, if, on the other hand $\sigma_i < \sigma_j$ we can see that $\frac{\partial \beta_1}{\partial \sigma_i} > 0$.

If $0 < \frac{\sigma_i}{\sigma_j} = \rho_{ij} \leq 1$ then it follows that $\frac{\partial \beta_1}{\partial \sigma_i} = 0$.

ANNEX 3: PROOF OF PROPOSITION 2

Totally differentiate (27) with respect to δ_i

$$\frac{\partial Q(\beta)}{\partial \beta_1}\frac{\partial \beta_1}{\partial \delta_i} + \frac{\partial Q(\beta)}{\partial \Delta}\frac{\partial \Delta}{\partial \delta_i} + \frac{\partial Q(\beta)}{\partial \delta_i} = 0 \qquad (40).$$

Because $\frac{\partial Q_\beta}{\partial \delta_f} = 0$ and $\frac{\partial Q_\beta}{\partial \delta_h} = -1$ it follows that

$$\frac{\partial \beta_1}{\partial \delta_f} = \frac{\beta_1}{Q'_\beta} > 0 \qquad (41)$$

$$\frac{\partial \beta_1}{\partial \delta_h} = \frac{1-\beta_1}{Q'_\beta} < 0 \qquad (42)$$

with $Q'_\beta = \partial Q(\beta) / \partial \beta_1$.

From (10) and (13) it can be seen that

$$\frac{\partial \delta_i}{\partial \sigma_i} = \phi \rho_{s\pi_i} \frac{\varphi}{1-\varphi} - \sigma_i \frac{\varphi}{(\varphi-1)^2} \qquad (43).$$

From (43) it follows that $\frac{\partial \delta_i}{\partial \sigma_i} < 0$ if $\rho_{s\pi_i} \leq 0$ or if $\sigma_i > \phi \rho_{s\pi_i}(1-\varphi)$ with $\rho_{s\pi_i} > 0$. In all other cases it will hold that $\frac{\partial \delta_i}{\partial \sigma_i} \geq 0$.

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Table 1: π_f^* for various values of σ_h , ρ_{fh} , $\rho_{s\pi_f}$ and $\rho_{s\pi_h}$ [1]

Panel A: ρ_{fh} =-0.75	***A1*** $\rho_{s\pi_f}$ =-0.75			***A2*** $\rho_{s\pi_f}$ =0.75		
$\rho_{s\pi_h}$	- 0.75	0	0.75	- 0.75	0	0.75
Level of π_f^*						
$\sigma_h = 0.05$	1.2165	1.2005	1.1867	1.3862	1.3483	1.3160
$\sigma_h = 0.15$	1.5307	1.4091	1.3309	1.8780	1.6453	1.4985
$\sigma_h = 0.25$	2.5825	1.8647	1.5814	3.4465	2.2778	1.8180
Slope: $\partial\pi_f^* / \partial\sigma_h$						
$\sigma_h = 0.05$	0.0199	0.0150	0.0112	0.0321	0.0216	0.0139
$\sigma_h = 0.15$	0.0528	0.0303	0.0191	0.0805	0.0426	0.0244
$\sigma_h = 0.25$	0.2413	0.0739	0.0345	0.3550	0.1018	0.0440
Panel B: ρ_{fh} =0.75	***B1*** $\rho_{s\pi_f}$ =-0.75			***B2*** $\rho_{s\pi_f}$ =0.75		
$\rho_{s\pi_h}$	- 0.75	0	0.75	- 0.75	0	0.75
Level of π_f^*						
$\sigma_h = 0.05$	1.1078	1.0994	1.0921	1.2288	1.2009	1.1781
$\sigma_h = 0.15$	1.1032	1.0748	1.0584	1.3259	1.1866	1.1201
$\sigma_h = 0.25$	1.3963	1.1680	1.1020	2.2161	1.4497	1.2096
Slope: $\partial\pi_f^* / \partial\sigma_h$						
$\sigma_h = 0.05$	-0.0045	-0.0059	-0.0068	-0.0023	-0.0083	-0.0119
$\sigma_h = 0.15$	0.0071	0.0024	0.0007	0.0342	0.0096	0.0017
$\sigma_h = 0.25$	0.0929	0.0223	0.0097	0.2210	0.0545	0.0190

[1] Model data: $\pi_h = m = 1$, $r = 0.10$, $\phi = 0.30$, $\varphi = 0.5$, $\sigma_f = 0.20$, $\alpha_h = 0.10$, $\alpha_f = 0.05$.

Table 2: π_f^* for various values of σ_f, ρ_{fh}, $\rho_{s\pi_h}$ and $\rho_{s\pi_f}$[2]

Panel A:	***A1***			***A2***		
ρ_{fh} =-0.75	$\rho_{s\pi_h}$ =-0.75			$\rho_{s\pi_h}$ =0.75		
$\rho_{s\pi_f}$	-0.75	0	0.75	-0.75	0	0.75
Level of π_f^*						
$\sigma_f = 0.05$	1.7626	1.8328	1.9063	1.2894	1.3109	1.3342
$\sigma_f = 0.15$	1.8394	2.0299	2.2450	1.3907	1.4574	1.5370
$\sigma_f = 0.25$	1.9005	2.1843	2.5271	1.4825	1.5916	1.7285
Slope: $\partial\pi_f^* / \partial\sigma_f$						
$\sigma_f = 0.05$	0.0083	0.0216	0.0362	0.0103	0.0148	0.0201
$\sigma_f = 0.15$	0.0068	0.0174	0.0308	0.0097	0.0141	0.0200
$\sigma_f = 0.25$	0.0052	0.0131	0.0250	0.0085	0.0125	0.0180
Panel B:	***B1***			***B2***		
ρ_{fh} =0.75	$\rho_{s\pi_h}$ =-0.75			$\rho_{s\pi_h}$ =0.75		
$\rho_{s\pi_f}$	-0.75	0	0.75	-0.75	0	0.75
Level of π_f^*						
$\sigma_f = 0.05$	1.5300	1.6011	1.6767	1.1575	1.1734	1.1916
$\sigma_f = 0.15$	1.2268	1.3833	1.6042	1.0743	1.0984	1.1382
$\sigma_f = 0.25$	1.1563	1.2911	1.5768	1.0781	1.1090	1.1679
Slope: $\partial\pi_f^* / \partial\sigma_f$						
$\sigma_f = 0.05$	-0.0371	-0.0239	-0.0084	-0.0134	-0.0114	-0.0084
$\sigma_f = 0.15$	-0.0169	-0.0164	-0.0051	-0.0025	-0.0022	-0.0007
$\sigma_f = 0.25$	0.0006	-0.0015	0.0001	0.0028	0.0040	0.0063

[2] Model data: $\pi_h = m = 1$, $r = 0.10$, $\phi = 0.30$, $\varphi = 0.5$, $\sigma_h = 0.20$, $\alpha_h = 0.10$, $\alpha_f = 0.05$.

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