Local content and emission taxes when the number of foreign firms is endogenous

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Abstract

There is a wide range of countries which have employed local content requirements to promote jobs and meet national green energy objectives. At the same time market-based policies (e.g., emission taxes) have been implemented to address environmental degradation. This paper considers a Cournot model in the presence of emission taxes and local content requirements where the number of foreign, more efficient firms, is endogenous. The analysis explores conditions under which an emission tax and/or local content may lower emissions and encourage foreign direct investment. The analysis of policy reform is also explored.

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1 Introduction

There is a wide range of developing countries which have employed local content requirements to promote employment and stimulate the development of industries (for specific cases see e.g., UNIDO 1986, 2011a and 2011b; Sturgeon 1998; Lahiri and Ono 2003; Ado 2013; UNCTAD 2014). At the same time, developing countries face environmental issues and, as a result, some have implemented market-based policies such as emission/carbon taxes (e.g., Blackman and Harrington 2000; Shan and Larsen 1992; Tyler et al. 2013) as well as local content requirements to meet green energy objectives (UNCTAD 2014, pp. 19-26). The analysis of the interplay between development and environmental policy is thus relevant (Bowen 2012).

With these in mind, this paper examines the effects of emission taxes and local content requirements on emissions and foreign direct investment (FDI) where firms behave à la Cournot. The analysis explores the policy reform of emission taxes and local content requirements and, in addition, the conditions under which stricter/laxer local content and emission taxes aid in the reduction of emissions and increase in income via FDI.

The literature on FDI and environmental policy is vast, but the contribution of the present work lies at the intersection of two important strands (see Requate (2006) and Lambertini (2013) for a survey of the literature of environmental policy under imperfect competition). One strand examines whether FDI reduces pollution and increase output by foreign, less polluting firms. The idea here is that foreign firms bring in advanced, less polluting technology to the host country thereby lowering pollution (Zarsky 1999, p. 56). This hypothesis is referred to in the literature as the pollution halo hypothesis. Dardati and Saygili (2012) find evidence in the case of Chile that foreign firms are cleaner than domestic firms, Eskeland and Harrison (1997) find that foreign firms are more fuel efficient (i.e., use less dirty fuels) in the case of Morocco, Venezuela, Mexico and Cote dIvoire, and Blackman and Wu (1998) find similar evidence in the case of China. However, Neumayer (2001, p.17) argues that the evidence of the pollution halo hypothesis is ambiguous. Zarsky (1999) analyzes case studies around the world where foreign firms bring in better environmental practices, but larger environmental impacts might still be present. Gether and Melo (2004) list some of the mixed evidence on the pollution halo hypothesis.

With this empirical literature in mind, a theoretical literature, assuming Cournot competition, has emerged, which shows that stricter environmental regulation (absent of local content requirements) may not deter FDI (i.e., may not deter foreign firms from relocating to the host country) and the conditions under which this result holds (e.g., Dijkstra et al. 2011; Sanna-Randaccio and Sestini 2012; Elliot and Zhou 2012; Gautier 2017). The present paper adds to this line of research by considering an emission tax *and* local content requirement to examine the effects on both FDI and emissions. I derive conditions under which higher taxation may attract FDI, particularly in the presence of local content requirements.

The analysis also suggests, *inter alia*, that the government may respond to increasingly relatively pollution-intensive home firms by setting laxer taxation and local content requirements.[1] This is because relatively more pollution intensive home firms facilitate the entry of foreign, less pollution intensive firms, particularly under laxer policy. But in the case where the government uses entry incentives arising from the abatement induced by the emission tax to attract FDI, stricter taxation and stricter local content requirements are consistent with the promotion of FDI and addressing damages from pollution. This result shows the viability of stricter policy in the presence of free-entry and, additionally, the crucial role of free-entry in the characterization of policy.

This paper contributes, moreover, to a branch of the literature which examines the implications of policy on free-entry markets e.g., Matsumura and Okumura (2014), Kayalica and Lahiri (2005), Bayındır-Upmann (2003), Lahiri and Ono (1995, 2015), Requate (1997), Lee (1999), Conrad and Wang (1993), Katsoulacos and Xepapadeas (1995) to name a few.

[1] See DOC (2010) and Sterner and Köhlink (2015, p. 254) for examples of differences in pollution intensities within and across countries.

Matsumura and Okumura (2014), for example, show that under free entry quotas reduce welfare vis-à-vis taxes because quotas lead to excessive entry. In contrast, the present analysis indicates that an emission tax may not only control for excessive entry, but also serve as an incentive for entry via the pollution abatement induced by the tax, particularly in the presence of entry-restrictive policies such as local content requirements. It is shown that some of the results are reversed in the case where the number of firms is fixed.

A second important strand touches on the role of the local content (absent of emission taxes) and firm location decisions i.e., foreign firms are determined endogenously e.g., Lahiri and Ono (1998, 2003, 2004), and Qiu and Tao (2001). In a sense the present work is closest to Lahiri and Ono (1998). There are two fundamental contributions to their work. First, the present work incorporates issues of local pollution and an emission tax, while Lahiri and Ono's work only looks at the local content and profit taxation. Second, I consider exogenous changes in the pollution intensity coefficient to analyze the effect on emissions and FDI arising from policy adjustments. The present work adds to this literature by exploring the conditions (e.g., efficiency and incentives to enter the market) under which policy adjustments of emission taxes *and* local content requirements address emissions and promote FDI.

The analysis contributes also to a small line of research, which studies aspects of policy reform of environmental policy under imperfect competition (e.g., Hoel 1991; Hatzipanayotou et al. 2005; Lahiri and Symeonidis 2007; Bhattacharya and Pal 2010; Gautier 2013, 2014). Specifically, there are no works which look at the role of the local content requirement on policy reform alongside environmental policy and so the present work fills this void.

This paper develops a two-stage game where the host government first sets the emission tax and local content simultaneously; on the second stage firms take policy as given and maximize profits by choosing the level of output and emissions in a Cournot-Nash fashion. Firms compete for the production of a homogeneous good, which is exported to a third market exclusively. Relative to foreign firms, domestic firms may be more, less or equally pollution intensive, and at the same time foreign firms are relatively more efficient. The relative efficiency of foreign firms and asymmetry of pollution intensities, coupled with the free entry and exit assumption of foreign firms, allows to focus the analysis on issues of FDI and emissions.

The paper is structured as follows. The next section presents the model, followed by the comparative statics exercise. In section 4 I examine the extent to which exogenous changes in the pollution intensity coefficient of domestic firms affect optimal policy, welfare, emissions and FDI. Section 5 explores the case where the number of foreign firms is exogenous. The last section concludes with suggestions for future research.

2 The Model

Consider an m number of foreign firms and an n number of home firms all of which operate in the home country. Firms (home and foreign firms) compete for the production of a homogeneous good which is exported to a third market exclusively.

The number of foreign firms is determined endogenously via the zero-profit condition, whereas the number of home firms is exogenous (section 5 assumes fixed number of foreign firms). The chief reason for the free-entry assumption of foreign firms is to capture the flow of foreign firms in and out of the home country, and thus the role of FDI.[2]

As in Lahiri and Ono (1998) I shall assume constant marginal costs c^h (c^f) for each home (foreign) firm and therefore unit cost are equal to marginal cost. Home firms employ inputs from the home country, but foreign firms may employ inputs from the home and foreign country. With this in mind let k^h (k^f) denote marginal cost when production takes

[2] The assumption of free entry/exit of foreign firms (but not home firms) is to facilitate the analysis of how foreign, more efficient and less pollution intensive, firms affect FDI and emissions. Under the assumption of more efficient foreign firms (see below) it is reasonable to assume that foreign, but not home, firms are more likely to have the ability to relocate.

place using all inputs from the home (foreign) country. The government in the home country may command foreign firms to employ a share, $\delta \in (0,1)$, of domestic inputs i.e., δ captures the extent of local content requirement.

Therefore, marginal production costs for each home firm $i (i = 1, \ldots, n)$ and each foreign firm $j (j = 1, \ldots, m)$ are given by

$$c_i^h = k_i^h \tag{1}$$

$$c_j^f = (1-\delta) k_j^f + \delta k_i^h \tag{2}$$

where $k^h > k^f$ i.e., foreign firms are assumed to be more efficient than home firms. Strict inequality is assumed to capture the role of the local content,δ, and the role of entry and exit of foreign, more efficient, firms on emissions and FDI.[3]

Each home firm i and each foreign firm j generate emissions, $e_l^z = \theta_l^z q_l^z - a_l^z$, for $z = h, f$; $l = i, j$; $i = 1, \ldots, n$; $j = 1, \ldots, m$. The term $\theta_l^z q_l^z$ denotes gross pollution by firm l from country z, where $\theta_l^z > 0$ captures pollution intensity and q_l^z output by each firm, and the term a_l^z captures units of pollution abated. As defined in Lahiri and Symeonidis (2007, p. 891), each firm undertakes pollution abatement activities which exhibit the following cost structure

$$h_l^z(a_l^z) = (\theta_l^z q_l^z - e_l^z)^2/2, \quad where \quad z = h, f; \quad l = i, j \tag{3}$$

where $a_l^z = \theta_l^z q_l^z - e_l^z$, $0 < h_l^{z\prime} = a_l^z$ and $h_l^{z\prime\prime} > 0$. This end-of-pipe cost structure allows to track the role of pollution intensity coefficients and the abatement induced by the tax, and at the same time obtain closed-form solutions. Each home firm i and foreign firm j faces an emission (identical) tax, t, for each unit of pollution it fails to abate. An identical tax assumes away issues of strategic environmental policy (these have been examined at length in the literature e.g., Ulph and Ulph 1996, 2007).

[3]Strictly speaking it is possible to have $k^h < k^f$. I assume away this possibility. This is because I am interested in analyzing the role of foreign, more efficient, firms (i.e., FDI) on emissions and output. That is, $c^f < c^h \Leftrightarrow (1-\delta)k^f + \delta k^h < k^h \Leftrightarrow k^f < k^h$.

Demand faced by each firm is derived from preferences such that

$$p = \alpha - \beta(q_1^h + \ldots + q_n^h) - \beta(q_1^f + \ldots + q_m^f) \tag{4}$$

The order of events is as follows. The government in the home country sets the emission tax and local content simultaneously by maximizing social welfare. The specific structure of the welfare function is discussed in section 4. Firms then take policy as given and maximize profits in a Cournot-Nash fashion. I shall assume an interior solution throughout. The model is solved through backward induction.

Each foreign and home firm chooses the level of output and emissions simultaneously in a Cournot-Nash fashion.[4] That is, each firm l from country z solves

$$\max_{q_l^z, e_l^z} \pi_l^z = (p - c_l^z)q_l^z - h_l^z - e_l^z t - f_l^z \quad where \quad z = h, f; \quad l = i, j \tag{5}$$

where f denotes fixed costs. Differentiation of (3) and (5) yields, under symmetry, the following first-order conditions for home firms

$$p - \beta q^h = c^h + h^{h\prime}\theta^h \tag{6}$$

$$h^{h\prime} = t \tag{7}$$

where $p = \alpha - \beta(nq^h + mq^f)$. These are the well-known maximization conditions which say that marginal revenue equals marginal production costs and marginal abatement costs, $h^{h\prime}$, equal the emission tax. Analogously, under symmetry first-order conditions for foreign firms are given by

$$p - \beta q^f = c^f + h^{f\prime}\theta^f \tag{8}$$

$$h^{f\prime} = t \tag{9}$$

The number of home firms is assumed to be fixed, but the number of foreign firms is determined by the zero-profit condition:

$$\pi_j^f = (p - c_j^f)q_j^f - h^f - e_j^f t - f_j^f = 0 \tag{10}$$

[4] The assumption of a simultaneous choice of output and emissions abstracts from issues of the strategic choice of abatement, which have been studied elsewhere e.g., Carlsson (2000), Poyago-Theotoky (2003), Yakita and Yamauchi (2011).

Substituting (7) into (6) and (9) into (8), and using (1) and (2) gives

$$p - \beta q^h = k^h + t\theta^h \tag{11}$$

$$p - \beta q^f = (1-\delta)k^f + k^h\delta + t\theta^f \tag{12}$$

The solution to the Cournot-Nash equilibrium is obtained sequentially using (11), (12), (7), (9), (3) and (10), which yields

$$\bar{q}^f = \sqrt{\frac{f^f - t^2/2}{\beta}} \tag{13}$$

$$\beta\bar{q}^h = -(1-\delta)(k^h - k^f) - t(\theta^h - \theta^f) + \beta\bar{q}^f \tag{14}$$

$$\bar{m} = \frac{1}{\sqrt{\beta(f^f - t^2/2)}}\left[\alpha - c^f + n(c^h - c^f) + t(n\theta^h - (n+1)\theta^f)\right] - (n+1) \tag{15}$$

where second-order conditions ensure stability and uniqueness of the equilibrium. Closed-form solutions are consistent with Lahiri and Ono (1998, p. 456). Emissions arising from home and foreign firms are given by

$$E^h = n\bar{e}^h, \quad where \quad \bar{e}^h = \theta^h\bar{q}^h - a^h, \; a^h = t \tag{16}$$

$$E^f = \bar{m}\bar{e}^f, \quad where \quad \bar{e}^f = \theta^f\bar{q}^f - a^f, \; a^f = t \tag{17}$$

As a result, total emissions generated in the home country from both foreign and domestic firms are defined as $E^T = E^h + E^f$.

This concludes the description of the model.

3 Comparative Statics

In this section I examine the effects of the tax, t, and the local content requirement, δ, on output and emissions. Specifically, comprative static results are derived first, followed by the analysis of the role of pollution intensities. Section 3.1 examines the case where pollution intensities are asymmetric and section 3.2 the case where pollution intensities are symmetric; results from section 3.2 will be relevant in subsequent analyses.

Differentiation of (13)-(15) with respect to the tax, t, gives (dropping the "-" for notational simplicity)

$$\begin{aligned} \partial q^f/\partial t &= -t/2\beta q^f < 0 && (18)\\ \partial m/\partial t &= \left(n\theta^h - (n+1)\theta^f\right)/q^f\beta + (m+n+1)t/2\beta(q^f)^2 && (19)\\ \partial q^h/\partial t &= -(\theta^h - \theta^f)/\beta - t/2\beta q^f && (20)\\ \partial Q^f/\partial t &= \left(n\theta^h - (n+1)\theta^f\right)/\beta + (n+1)t/2\beta q^f && (21) \end{aligned}$$

There are two key effects at play here. First, an increase in the tax raises abatement and profits, which prompts foreign firms to enter the market (last term in 19) and, as a result, output by foreign firms, Q^f, rises (last term in 21). Home firms react strategically by reducing output (i.e., the last term in 20, $t/2\beta q^f$). Second, firms with a relatively small (large) pollution intensity coefficient, θ, pay relatively less (more) in taxes, thereby having an impact on home and foreign output. Specifically, an increase in the tax renders home firms relatively less cost competitive, which results in lower output by home firms and, consequently, an increase in the number of foreign firms, m, and foreign output, Q^f, as foreign firms react strategically. But at the same time an increase in the tax raises taxes paid by foreign firms and thus profits, the number of foreign firms and foreign output fall, which results in an increase in the output of home firms as home firms react strategically.

The change in home emissions, E^h, and foreign emissions, E^f, are derived next. Differentiation of (16) and (17), and using (18)-(21) gives

$$dE^h = nd\bar{e}^h = \left[\frac{-n\theta^h(\theta^h - \theta^f)}{\beta} - \frac{nt\theta^h}{2\beta q^f} - n\right] dt \quad (22)$$

$$\begin{aligned} dE^f &= md\bar{e}^f + \bar{e}^f dm \\ &= \left[-\frac{mt\theta^f}{2\beta q^f} - m + \frac{e^f}{q^f}\left[\frac{n(\theta^h - \theta^f)}{\beta} + \frac{nt}{2\beta q^f} - \frac{\theta^f}{\beta} + \frac{(m+1)t)}{2\beta q^f}\right]\right] dt \quad (23) \end{aligned}$$

Then, combining (22) and (23), and using $e^f = \theta^f q^f - a^f$, where $a^f = t$, yields the change in total emissions, $E^T = E^h + E^f$:

$$\begin{aligned} dE^T &= \Bigg[-\frac{n(\theta^h-\theta^f)^2}{\beta} + \frac{t\left(-n\theta^h+\theta^f(n+1)\right)}{2\beta q^f} - m - \frac{\theta^f e^f}{\beta q^f} - n \\ &\quad -\frac{nt(\theta^h-\theta^f)}{\beta q^f} - \frac{t^2(m+n+1)}{2\beta(q^f)^2}\Bigg] dt \end{aligned} \tag{24}$$

The analysis of (22)-(24) is presented in sections 3.1 and 3.2.

The derivation of comparative static effects with respect to the local content requirement, δ, are presented next. Differentiation of (13)-(15) yields

$$\partial q^f/\partial\delta = 0 \qquad \partial m/\partial\delta = -(k^h-k^f)(n+1)/\beta q^f < 0 \tag{25}$$

$$\partial q^h/\partial\delta = (k^h-k^f)/\beta > 0 \qquad \partial Q^f/\partial\delta = -(k^h-k^f)(n+1)/\beta < 0 \tag{26}$$

An increase in the local content increases (decreases) output of home (foreign) firms; additionally, foreign firms exit the market with a higher content requirement. Intuitively, an increase in the local content renders foreign firms relatively less cost competitive and, as a result, they exit the market thereby prompting home firms to react strategically and raise output. It is noteworthy that as domestic and foreign firms become equally efficient (i.e., $k^h \simeq k^f$), then the effect of the local content becomes negligible since differences in cost competitiveness across firms become small. These results are consistent with the literature e.g., Lahiri and Ono (1998).

The effect on emissions is given by differentiating (16) and (17):

$$dE^h = nde^h = \frac{1}{\beta}\left[n\theta^h(k^h-k^f)\right] d\delta \tag{27}$$

$$\begin{aligned} dE^f &= mde^f + e^f dm \\ &= -\frac{1}{\beta q^f}\left[e^f(n+1)(k^h-k^f)\right] d\delta \\ &= -\frac{(k^h-k^f)}{\beta}\left[(n+1)\theta^f - (n+1)t/q^f\right] d\delta \end{aligned} \tag{28}$$

where $e^f = \theta^f q^f - t$. Combining (27) and (28) the change in total emissions via the local content is given by

$$dE^T = \frac{(k^h - k^f)}{\beta}\left[n\theta^h - \theta^f(n+1) + \frac{t(n+1)}{q^f}\right]d\delta \tag{29}$$

The analysis of (27)-(29) is presented in sections 3.1 and 3.2.

3.1 Asymmetric pollution intensities ($\theta^h \neq \theta^f$)

This section examines the effects on output and emissions in the case where pollution intensities across firms are not equal.

If home firms are relatively more pollution intensive (i.e., $\theta^h/\theta^f > (n+1)/n$), then using (18)-(21) with an increase in the tax home output falls but foreign output and the number of foreign firms rise. This is both because home firms are less cost competitive (exhibit a larger pollution intensity) *and* the abatement induced by the tax prompts the entry of foreign firms.

With this in mind I touch on the issue raised earlier, *viz.*, the effect of a tax increase on total emissions. There are several results which can be derived from (22), (23) and (24). First, total emissions, $E^T = E^h + E^f$, fall as long as the pollution intensity coefficient of home firms lies within a certain range i.e., $\theta^h > \theta^f$ and $(n+1)\theta^f > n\theta^h + (m+n+1)t/2q^f$. Intuitively, a relatively large intensity coefficient of home firms ($\theta^h > \theta^f$) ensures a reduction in emissions from home firms, E^h; and a relatively large intensity coefficient of foreign firms (i.e., $(n+1)\theta^f > n\theta^h + (m+n+1)t/2q^f$) ensures a reduction in the number of and emissions by foreign firms, E^f.[5] Second, if home firms exhibit a relatively large intensity coefficient in the sense that $n\theta^h > (n+1)\theta^f$, then total emissions, E^T, fall. This is because a large θ^h lowers pollution by home firms, E^h, and this effect is sufficiently large to offset the increase in emissions that takes place via the entry of foreign firms (recall that if home firms are more

[5] To see this, note that if $\theta^h > \theta^f$, then E^h falls with the tax. Additionally, m falls (and so does E^f) with the tax if $(n+1)\theta^f > n\theta^h + (n+m+1)t/2q^f$, which is consistent with $\theta^h > \theta^f$.

pollution intensive this will prompt foreign firms to enter the market). That is, from (24) $dE^T < 0$, if $\theta^h n > \theta^f(n+1)$.

The aforementioned results are consistent with the literature (e.g., Ebert (1992), Requate (2006), Gautier (2017)).

Proposition 3.1. *Let $\theta^h \neq \theta^f$. Then, total emissions fall with an increase in the emission tax if home firms are sufficiently more pollution intensity i.e., $\theta^h n > \theta^f(n+1)$.*

As for the local content, I use (27) and (28): home emissions, E^h, rise with an increase in the local content via changes in home output, but foreign emissions, E^f, fall via a reduction in the number of foreign firms. It is noteworthy that although the number of foreign firms falls with the local content, there are two opposing effects at play. On the one hand, an increase in the local content raises marginal costs, lowers foreign profits and, as a result, foreign firms exit the market thereby reducing foreign output and emissions (i.e., $(n+1)\theta^f$). On the other, with the reduction in foreign output foreign firms pollute less and therefore pay less in taxes, which in turn raises profits, the number of foreign firms and emissions (i.e., $(n+1)t/q^f$). But this latter effect is completely offset by the former and, as a result, foreign output and emissions fall with the local content. Moreover, using (29) total emissions rise if home firms are relatively more pollution intensive i.e., $n\theta^h > (n+1)\theta^f$, but fall if foreign firms are relatively more pollution intensive i.e., $(n+1)\theta^f > n\theta^h + t(n+1)/q^f$. This is because with relatively pollution intensive home (foreign) firms the increase (decrease) in emissions by home (foreign) firms completely offsets the reduction (increase) in foreign (home) emissions.

Proposition 3.2. *Let $\theta^h \neq \theta^f$. Then, total emissions rise with an increase in the local content if home firms are relatively more pollution intensive i.e., $n\theta^h > (n+1)\theta^f$.*

There are a number of policy reforms through which total emissions fall in the case where $\theta^h \neq \theta^f$ thus illustrating the role of relative pollution intensities and the design of policy. For instance, an increase in the emission tax ($dt > 0$) and a decrease in the content requirement ($d\delta < 0$) lowers total emissions, if domestic firms are relatively more pollution intensive ($n\theta^h > \theta^f(n+1)$).[6]

Proposition 3.3. *Let $\theta^h \neq \theta^f$. Then, an increase in the emission tax ($dt > 0$) and decrease in the content requirement ($d\delta < 0$) reduce total emissions, if domestic firms are relatively more pollution intensive i.e., $n\theta^h > \theta^f(n+1)$.*

3.2 Symmetric pollution intensities ($\theta^h = \theta^f = \tilde{\theta}$)

If, alternatively, pollution intensities are equal across firms, then using (18)-(21) home output falls with a tax increase: with identical pollution intensities differences in tax payments become negligible and so the reduction in home output takes place via the entry of foreign firms arising from the abatement induced by the tax. Moreover, with identical pollution intensities foreign output and the number of foreign firms fall (rise), if the pollution intensity is sufficiently large (small) i.e., $\tilde{\theta} > (m+n+1)t/2q^f$ ($\tilde{\theta} < (n+1)t/2q^f$). This effect on foreign output and number of firms points to the role of abatement incentives and free-entry via the emission tax.

Proposition 3.4. *Let $\theta^h = \theta^f = \tilde{\theta}$. Then, an increase in the emission tax raises the number of foreign firms and total foreign output if the pollution intensity is sufficiently small i.e., $\tilde{\theta} < t(n+1)/2q^f$.*

With identical pollution intensities the reduction in foreign output, and at the same time home output, offsets any increase in emissions arising from the entry of foreign firms, thereby lowering total emissions. In particular, imposing the condition $\theta^h = \theta^f = \tilde{\theta}$ on (22)

[6] Additionally, with $\theta^h \neq \theta^f$, $dt > 0$, and $d\delta > 0$ lower total emissions, if foreign firms are relatively more pollutant. To see this notice it requires three conditions. First, that total emissions fall with the tax if $(n+1)\theta^f > n\theta^h + t(m+n+1)/2q^f$, which implies $(n+1)\theta^f > n\theta^h + t(n+1)/2q^f$; second, total emissions fall with the content requirement, if $(n+1)\theta^f > n\theta^h + t(n+1)/q^f$, which implies $(n+1)\theta^f > n\theta^h + t(n+1)/2q^f$; and third, $\theta^h > \theta^f$. All these three conditions are consistent with each other.

and (23) gives (subscript denotes partial derivative)

$$
\begin{aligned}
E_t^T &= \left[\frac{e^f}{\beta q^f}\left(-\tilde{\theta}+\frac{t(n+m+1)}{2q^f}\right)-(m+n)\left(\frac{t\tilde{\theta}}{2\beta q^f}+1\right)\right] \\
&= -\frac{e^f}{\beta q^{f2}}\left(\tilde{\theta}q^f-t+t/2\right)-(m+n)\left(\frac{t^2}{2\beta q^f}+1\right)<0 \qquad (30)
\end{aligned}
$$

where $e^f=\tilde{\theta}q^f-t>0$.

Proposition 3.5. *Let $\theta^h=\theta^f=\tilde{\theta}$. Then, total emissions fall with a tax increase (i.e., $E_t^T<0$) for any $\tilde{\theta}$.*

As for the local content in (29), if firms are equally pollution intensive (i.e., $\theta^h=\theta^f=\tilde{\theta}$), then total emissions fall with an increase in the local content *if and only if* $\tilde{\theta}$ is large enough ($\tilde{\theta}>t(n+1)/q^f$). This is because the reduction in foreign emissions resulting from the exit of foreign firms completely offsets the increase in home emissions induced by an increase in the local content. Analogously, an increase in the local content raises total emissions if the abatement induced by the tax is large ($\tilde{\theta}<t(n+1)/q^f$): in this case the exit of foreign firms, arising from an increase in the local content, results in a sufficiently large reduction in total abatement and thus an increase in emissions.

Proposition 3.6. *Let $\theta^h=\theta^f=\tilde{\theta}$. Then, an increase in the local content raises total emissions if and only if the pollution intensity is relatively small i.e., $E_\delta^T>0\Leftrightarrow\tilde{\theta}<t(n+1)/q^f$.*

In the case where firms are equally pollution intensive the condition $\tilde{\theta}<t(n+1)/2q^f$ is consistent with $m_t>0$ (i.e., the number of foreign firms rises with a tax increase) and $E_\delta^T>0$. The implication here is that propositions 3.6 and 3.4 ensure $E_\delta^T>0$ and $m_t>0$; and consistent with these proposition 3.5 ensures $E_t^T<0$.

Proposition 3.7. *Let $\theta^h=\theta^f=\tilde{\theta}$. A small pollution intensity (i.e., $\tilde{\theta}<t(n+1)/2q^f$) is consistent with the number of foreign firms rising with an increase in the emission tax (i.e., $m_t>0$) and total emissions rising with the local content i.e., $E_\delta^T>0$.*

With the aforementioned results in mind, it can be shown that total emissions may fall via policy reform; that is, via the decrease/increase of the tax/local content. As an example, the following proposition is stated, which underscores the role of the abatement incentives via the emission tax.

Proposition 3.8. *Let $\theta^h = \theta^f = \tilde{\theta}$. Then, an increase in the emission tax ($dt > 0$) and decrease in the content requirement ($d\delta < 0$) reduce total emissions as long as $t(n+1)/q^f > \tilde{\theta}$.*

4 Policy response and pollution-intensive domestic firms

In this section I examine the extent to which the optimal emission tax, t, and local content, δ, are sensitive to the pollution intensity coefficient. The strategy here is to determine the conditions under which the tax and local content rise or fall with an exogenous change in the pollution intensity coefficient of domestic firms, θ^h, starting from an equilibrium where foreign and domestic firms are equally pollution intensive i.e., $\theta^h = \theta^f$. This approach seeks to characterize the case where home firms become relatively more pollution intensive and in this way examine the role of foreign, more efficient firms. Since the literature has characterized both the optimal emission tax (e.g., Requate 2006; Sanna-Randacccio and Sestini 2012; Bayındır-Upmann 2003) and local content requirement (e.g., Lahiri and Ono 1998, 2003) and, moreover, since the main focus of the present analysis is on aspects of FDI and changes in emissions, I shall proceed under the assumption of an interior solution for t and δ. The analysis relies also on the following two assumptions.

Assumption 4.1. *Home firms are not too inefficient (i.e., $k^h < 2k^f$).*

Assumption 4.2. *The pollution intensity is small (i.e., $\tilde{\theta} < t(n+1)/2q^f$) and thus $E^T_\delta > 0$ and $m_t > 0$.*

The role of the condition $k^h < 2k^f$ in assumption 4.1 is key: it says that with not too inefficient home firms a decrease (increase) in the tax (local content) increases profits and income (defined below). The analysis proceeds under this assumption about relative efficiency to facilitate the derivation of policy implications. Additionally, assumption 4.2 indicates that in order to examine the role of free-entry via the abatement induced by the tax I shall focus on the case where the pollution intensity is small (i.e., $\tilde{\theta} < t(n+1)/2q^f$), where $E_\delta^T > 0$ and $m_t > 0$ as indicated by proposition 3.7.

4.1 Welfare

Consider the government of the home country, which is concerned with addressing damages from pollution. At the same time the government seeks to raise home profits as well as income from foreign and domestic firms. Since firms operating in the home country (foreign and home firms) export to a third market, consumer surplus effects are assumed away. The assumption about export-oriented firms is made for two reasons; first, it allows to specifically capture the role of export-oriented FDI, and second, it facilitates comparisons with the existing literature e.g., Ulph (1996), Lahiri and Ono (2003), Gautier (2017).

The government chooses the local content and emission tax simultaneously so as to solve the following welfare maximization problem:

$$\max_{t,\delta} W = n\pi^h + tE^T + nq^h k^h + \delta k^h Q^f - \varphi(E^T) \tag{31}$$

where total emissions are given by $E^T = E^f + E^h$, and the damage function φ satisfies $\varphi' > 0$, $\varphi'' > 0$. As in Lahiri and Ono (1998) income is given by $I = nq^h k^h + \delta k^h Q^f$. The first (second) term in I represents income arising from output produced by home (foreign) firms employing inputs from the home country.

First-order conditions are given by (subscripts denote partial derivatives):

$$W_t = n\pi_t^h + I_t + E^T + (t - \varphi')E_t^T = 0 \tag{32}$$

$$W_\delta = n\pi_\delta^h + I_\delta + (t - \varphi')E_\delta^T = 0 \tag{33}$$

The analysis is restricted to the case where (32) and (33) yield an interior solution, which consists of a tax, $t^* > 0$, and local content, $\delta^* \in (0, 1)$. I shall assume strict concavity in the welfare function $W(t, \delta)$, satisfying $W_{tt} < 0$, $W_{\delta\delta} < 0$, $W_{tt}W_{\delta\delta} - W_{t\delta}W_{\delta t} > 0$.

Using the first-order conditions and assumption 4.1 the following proposition is stated (see appendix for a derivation).

Proposition 4.1. *Let $\theta^h = \theta^f$. Then, consistent with welfare maximization (i) the optimal tax is less than marginal damages and (ii) total emissions fall with a reduction in the local content.*

This proposition is important in the upcoming analysis because the focus is on the case where home firms become relatively more pollution intensive: an increase in the pollution intensity, θ^h, starting at $\theta^h = \theta^f$.

4.2 Pollution intensity and welfare

A key building block of the analysis is the characterization of welfare as a function of the pollution intensity i.e., $W = W(\theta^h)$. The reason for doing this is twofold. First, it allows to examine changes in total emissions, profits and income without policy adjustments. Second, by looking at changes in total emissions, profits and income (for given tax and local content) it is possible to analyze potential policy response of either policy or a combination of the two.[7] For example, if for a given range of pollution intensities total emissions rise as home

[7] Even though an increase in θ^h, starting from the Nash equilibrium at $\theta^h = \theta^f$, induces changes in both the tax and local content (envelope theorem), the case where only one policy change is considered (either a tax or local content) can be thought of as a case where one of the two policies does not change too much e.g., the tax responds to a change in θ^h, but the local content's response is very small.

firms become more pollution intensive, then a potential policy response from the government could be to raise the emission tax. This approach, therefore, provides a flexible framework to analyze the driving factors behind the policy response.

In particular, consider (31) as a function of θ^h. Then, for given tax, $t > 0$, and local content, $0 < \delta < 1$, differentiation gives

$$W_{\theta^h} = n\pi^h_{\theta^h} + I_{\theta^h} + (t - \varphi')E^T_{\theta^h} \tag{34}$$

$$W_{\theta^h\theta^h} = n\pi^h_{\theta^h\theta^h} + (t - \varphi')E^T_{\theta^h\theta^h} - \varphi''(E^T_{\theta^h})^2 = 2tn\varphi'/\beta - \beta\varphi''(E^T_{\theta^h})^2 \tag{35}$$

where $I_{\theta^h} = -k^h tn(1-\delta) < 0$, $E^T_{\theta^h\theta^h} = -2nt/\beta < 0$, $\pi^h_{\theta^h} = -2tq^h < 0$, $\pi^h_{\theta^h\theta^h} = 2nt^2/\beta > 0$. The rest of the terms are explained below. The function $W(\theta^h)$ is strictly convex *if and only if* $2tn\varphi' > \beta^2\varphi''(E^T_{\theta^h})^2$.

Figure 1 illustrates some of the features of the model using equations (34) and (35). First, income, I, and profits, π^h, are decreasing functions of θ^h. This is because an increase in the pollution intensity coefficient of home firms, *ceteris paribus*, results in more foreign firms entering the market, higher tax payments by home firms and, therefore, a reduction in home profits and output. Additionally, income falls with an increase in θ^h because the income (share δ) generated by foreign firms (i.e., larger θ^h results in more income from foreign firms as these become more cost competitive and enter the market) is completely offset by the reduction in income from lower home output.[8]

Third, in figure 1 the strict concavity of total emissions indicates two opposing effects. To see this consider (16) and (17) where the change in total emissions with respect to θ^h is given by

$$E^T_{\theta^h} = nq^h + n\theta^h q^h_{\theta^h} + (\theta^f q^f - t)tn/q^f\beta \tag{36}$$

where the first term, nq^h, captures the increase in emissions for any level of output, and the second the reduction in emissions as home output falls with an increase in the pollution

[8]Income is non-negative. To see this, suppose income is equal to zero i.e., $I = 0$. Hence, $nq^h + \delta q^f m = 0$ which implies $nq^h/mq^f = -\delta$. But this is a contradiction under the non-negativity assumption of δ, q^h and q^f.

intensity of home firms, $n\theta^h q^h_{\theta^h} < 0$. The third term consists of two opposing effects: emissions rise as more foreign firms enter the market, $\theta^f tn/\beta$, but also emissions fall via more abatement as foreign firms enter the market, $-t^2 n/q^f \beta$. Moreover, from (36) total emissions is strictly concave in θ^h (i.e., for any θ^h, $E^T_{\theta^h\theta^h} = -2nt/\beta < 0$, if $t > 0$) and at $\theta^h = 0$, $E^T_{\theta^h} > 0$.[9] As a result, there is a θ^h_E such that $E^T_{\theta^h} = 0$.

Then, at $\theta^h = \theta^f$ (36) simplifies to

$$\begin{aligned} E^T_{\theta^h}\big|_{\theta^h=\theta^f} &= nq^h + n\theta q^h_{\theta^h} + (\theta q^f - t)tn/q^f\beta \\ &= nq^h - n\theta t/\beta + (\theta q^f - t)tn/q^f\beta \\ &= nq^h - t^2 n/q^f\beta \end{aligned} \tag{37}$$

The first term captures the increase in emissions at any q^h, and the second the reduction in emissions arising from additional abatement as foreign firms enter the market. Therefore, at $\theta^h = \theta^f$, on the one hand, total emissions increase at every level of output as domestic firms become more pollution intensive. But on the other hand, the entry of foreign firms raises abatement thus reducing emissions. Total emissions fall at an increasing rate after a threshold, θ^h_E. This is because for large pollution intensities the entry of foreign firms is sufficiently large so as to reduce emissions.

Proposition 4.2. *Starting at $\theta^h = \theta^f$ there is a θ^h_E such that (i) $E^T_{\theta^h} = 0$, (ii) $E^T_{\theta^h} > 0$, for $\theta^h < \theta^h_E$, and (iii) $E^T_{\theta^h} < 0$, for $\theta^h > \theta^h_E$.*

We are now in position to delve into the characteristics of (34) and (35). First, recall that $\pi^h_{\theta^h} < 0$ and $I_{\theta^h} < 0$. Second, from proposition 4.1 the optimal tax is less than marginal damages at $\theta^h = \theta^f$ as long as home firms are not too inefficient i.e., $k^h < 2k^f$, assumption 4.1. Third, from proposition 4.2 for any $\theta^h \in (0, \theta^h_E)$, $E^T_{\theta^h} > 0$ and $E^T_{\theta^h} = 0$ at θ^h_E. With these in mind it follows from (34) and (35) that at $\theta^h = \theta^f$ $W_{\theta^h}|_{\theta^h \leq \theta^h_E} < 0$ and $W_{\theta^h\theta^h}|_{\theta^h = \theta^h_E} > 0$. The key here is that the analysis of policy response is relevant for the range of pollution

[9] By construction $\theta^h \neq 0$, but the expression in (36) is evaluated at $\theta^h = 0$ to get a feel for the function $E^T(\theta^h)$. Additionally, $e > 0 \Rightarrow \theta > t/q > 0$.

intensities where the welfare function is decreasing in θ^h. The following proposition states this result.

Proposition 4.3. *Starting at $\theta^h = \theta^f$ welfare is a decreasing function ($W_{\theta^h} < 0$) for the range of pollution intensity $\theta^h \in (0, \theta^h_E]$.*

In addition, if $\theta^h > \theta^h_E$ then $E^T_{\theta^h} < 0$ and so $W_{\theta^h} < 0$ *if and only if* $n\pi^h_{\theta^h} + I_{\theta^h} < 0$; that is, for large pollution intensity welfare is a decreasing function as long as the reduction in income and profit is large. I shall focus on this case since the analysis of policy is relevant as long as welfare decreases with θ^h. I state this more formally in the following proposition.

Proposition 4.4. *Starting at $\theta^h = \theta^f$ there is a pollution intensity, θ^h_u, such that $E^T_{\theta^h}\big|_{\theta^h \in (\theta^h_E, \theta^h_u)} < 0$ and $W_{\theta^h}\big|_{\theta^h \in (\theta^h_E, \theta^h_u)} < 0$.*

The key implication from proposition 4.4 is that θ^h_u represents an upper-bound where welfare is a decreasing function of the pollution intensity coefficient (for given tax and local content), where the analysis of policy is relevant since welfare is non-increasing. In what follows the analysis proceeds under proposition 4.4.

4.3 Pollution intensity and the tax with fixed local content

This section examines changes in the optimal emission tax (for given local content) resulting from home firms becoming relatively more pollution intensive. That is, starting from $\theta^h = \theta^f$ I analyze the sign of t_{θ^h} (subscripts denote partial derivatives). The analysis indicates, *inter alia*, that the tax rises as home firms become relatively more pollution intensive if the need to tackle rising emissions and encourage the entry of foreign firms is large.

Differentiation of the first-order condition $W_t(t(\theta^h), \theta^h) = 0$ yields (subscripts denote partial derivatives)

$$-W_{tt} t_{\theta^h} = W_{t\theta^h} = n\pi^h_{t\theta^h} + I_{t\theta^h} + E^T_{\theta^h} + (t - \varphi')E^T_{t\theta^h} - \varphi'' E^T_t E^T_{\theta^h} \qquad (38)$$

where $E^T_{t\theta^h} < 0$, $E^T_t < 0$, $W_{tt} < 0$ by the concavity assumption of the $W(t, \delta)$ function and $\varphi' > 0$, $\varphi'' > 0$ by the convexity assumption of the damage function. Moreover, at $\theta^h = \theta^f$, $n\pi^h_{t\theta^h} + I_{t\theta^h} + E^T_{\theta^h} < 0$. The sign of $W_{t\theta^h}$ dictates the sign of t_{θ^h} at $\theta^h = \theta^f$. The first three terms in (38) capture the incentive to lower the tax to encourage profits and income. The fourth term captures efforts by the government to adjust the number of foreign firms, but also address damages from pollution. The fifth term denotes efforts to tackle damages from pollution.

I shall consider two cases using proposition 4.2. The first case examines policy response for a range of $\theta^h < \theta^h_E$, where $E^T_{\theta^h} > 0$ i.e., emissions rise, and income and profits fall as home firms become relatively more pollution intensive. The second case consists of a range of $\theta^h > \theta^h_E$ where $E^T_{\theta^h} < 0$ i.e., emissions fall, and income and profits still fall.[10]

In the case $\theta^h < \theta^h_E$, where $E^T_{\theta^h}\big|_{\theta^h=\theta^f} > 0$, there are two opposing effects highlighted in equation (38). First, an increase in θ^h raises total emissions and therefore the government raises the tax. But also the government raises the tax to encourage the entry of foreign firms: this is because with a large abatement (i.e., $\tilde{\theta} < t(n+1)/2q^f$, assumption 4.2) and a tax set below marginal damages (i.e., $t - \varphi' < 0$) the number of foreign firms, in equilibrium, is smaller and, therefore, a tax increase induces abatement and consequently foreign firms into the market. Second, an increase in θ^h reduces profits and income and, as a result, the government lowers the tax to encourage income and profits. Therefore, the government raises the tax (i.e., $t_{\theta^h}\big|_{\theta^h=\theta^f} > 0$) *if and only if* the incentives to bring in foreign firms *and* tackle emissions are large.

In the case $\theta^h > \theta^h_E$, where $E^T_{\theta^h}\big|_{\theta^h=\theta^f} < 0$, there are also two opposing effects. First, an increase in θ^h reduces profits and income and, as a result, the government lowers the tax. In this case there is more room to lower the tax since total emissions fall for $\theta^h > \theta^h_E$. Second, the government raises the tax to encourage the entry of foreign firms. Therefore,

[10] Since the objective here is to analyze the policy response resulting from a change in θ^h (starting from $\theta^h = \theta^f$), I rule out values of θ^h where welfare rises i.e., $\theta^h \geq \theta^h_u$.

the government raises the tax (i.e., $t_{\theta^h}|_{\theta^h=\theta^f} > 0$) *if and only if* the incentives to promote the number of foreign firms is sufficiently large.

Proposition 4.5. *Starting at $\theta^h = \theta^f$ an increase in θ^h (i.e., as home firms become relatively more pollution intensive) raises the tax (for given local content) as long as the incentive to attract foreign firms is sufficiently large.*

One implication of proposition 4.5 is that the tax is increased by the government as long as the incentives to attract foreign firms is large, both in the case where industry is not too pollution intensity (i.e., $\theta^h < \theta^h_E$) as well as in the case where industry is very pollution intensive (i.e., $\theta^h > \theta^h_E$). This is because vis-à-vis home firms, foreign firms are relatively less pollution intensive as well as relatively more efficient.

Corollary 4.1. *An increase in θ^h is more likely to result in an increase in the tax by the government when the industry is not too pollution intensive i.e., $\theta^h < \theta^h_E$.*

The implication of Corollary 4.1 is that in low pollution intensive industries, as home firms become relatively more pollution intensive, the tax is more likely to be adjusted upwards because of the incentives to tackle emissions *and* bring in more efficient and less pollution intensive foreign firms.

4.4 Pollution intensity and local content with fixed emission tax

Analogous to the case of the tax in section 4.3, this section examines the extent to which the local content changes (for given tax) with changes in the intensity coefficient of home firms, starting from a situation where foreign and home firms are equally pollution intensive. It is shown that, similar to section 4.3, as home firms become relatively more pollution intensive the government lowers the local content as long as the incentives to bring in more foreign firms is sufficiently large. As before I shall consider two cases, namely, (i) $\theta^h < \theta^h_E$ and (ii) $\theta^h > \theta^h_E$ as defined in proposition 4.2.

To analyze changes in the local content (for given tax) I differentiate $W_\delta(\delta(\theta^h), \theta^h) = 0$, which yields (subscripts denote partial derivatives):

$$-W_{\delta\delta}\delta_{\theta^h} = W_{\delta\theta^h} = tn(2k^f - k^h)/\beta + (t - \varphi')E^T_{\delta\theta^h} - \varphi'' E^T_\delta E^T_{\theta^h} \tag{39}$$

where $W_{\delta\delta} < 0$ by the concavity assumption of the welfare function, $E^T_{\delta\theta^h} > 0$, and $tn(2k^f - k^h)/\beta = n\pi^h_{\delta\theta^h} + I_{\delta\theta^h}$. The first term in (39) captures the role of the local content to raise income and profits. From assumption 4.1 $k^h < 2k^f$ and so the first term in (39) is positive thus indicating that the government promotes income and profits by increasing the local content. The second term denotes the government's attempt to adjust the number of foreign firms with the local content, but also tackle changes in total emissions. The third term captures efforts by the government to tackle emissions.

In the case $\theta^h < \theta^h_E$, where $E^T_{\theta^h}\big|_{\theta^h=\theta^f} > 0$, there are two opposing effects underscored in equation (39). First, an increase in θ^h reduces income and profits and, therefore, the government raises the local content. This is because domestic firms are not too inefficient and so an increase in the local content raises income and profits. Second, an increase in θ^h raises total emissions and, as a result, the government lowers the local content to control emissions since $E^T_\delta > 0$ (assumption 4.2). The government also lowers the local content in order to encourage the entry of foreign firms.

In the case $\theta^h > \theta^h_E$, where $E^T_{\theta^h}\big|_{\theta^h=\theta^f} < 0$, there are two opposing effects. First, the government encourages the entry of foreign firms via a reduction in the local content. Second, an increase in θ^h reduces profits and income and, as a result, the government raises the local content to encourage income and profits. In this case the incentive to raise the local content is greater because emissions fall for $\theta^h > \theta^h_E$.

Proposition 4.6. *Starting at $\theta^h = \theta^f$ an increase in θ^h induces the government to decrease the local content (for given tax) as long as the incentive to attract foreign firms is sufficiently large.*

Corollary 4.2. *An increase in θ^h is more likely to result in a reduction in the local content when the industry is pollution intensive i.e., $\theta^h > \theta^h_E$.*

4.5 Pollution intensity, the local content and emission tax

The analysis in this section considers the possibility of changes in the tax (local content), not only arising from changes in the pollution intensity coefficient, but also the adjustments in the local content (tax). In particular, differentiation of $W_t(t(\theta^h), \delta(\theta^h), \theta^h) = 0$ and $W_\delta(t(\theta^h), \delta(\theta^h), \theta^h) = 0$ yields

$$\eta\, t_{\theta^h}|_{\theta^h=\theta^f} = -W_{t\theta^h} W_{\delta\delta} + W_{\delta\theta^h} W_{t\delta} \tag{40}$$

$$\eta\, \delta_{\theta^h}|_{\theta^h=\theta^f} = -W_{\delta\theta^h} W_{tt} + W_{t\theta^h} W_{\delta t} \tag{41}$$

where $W_{tt} < 0$, $W_{\delta\delta} < 0$ and $\eta = W_{tt}W_{\delta\delta} - W_{t\delta}W_{\delta t} > 0$ by the concavity of the welfare function, $W_{t\theta^h}$ is given by (38), $W_{\delta\theta^h}$ is given by (39), and $W_{t\delta} = W_{\delta t}$ is the new term where

$$W_{t\delta}|_{\theta^h=\theta^f} = n\pi^h_{t\delta} + I_{t\delta} + E^T_\delta + (t - \varphi')E^T_{t\delta} - \varphi'' E^T_t E^T_\delta \tag{42}$$

where $E^T_\delta > 0$, $E^T_t < 0$, $E^T_{t\delta} > 0$, $-\varphi' E^T_{t\delta} < 0$, $-\varphi'' E^T_t E^T_\delta > 0$, $n\pi^h_{t\delta} + I_{t\delta} + E^T_\delta + tE^T_{t\delta} > 0$. In general the sign of (42) is ambiguous, and captures the adjustment in the tax as a result of changes in the local content. The first three terms capture effects via profits, income and tax revenue; the fourth term effects associated with the number (entry and exit) of foreign firms; and the fifth term aspects of damages from pollution.

To see the effects on the tax adjustment via changes in the local content I analyze $W_{\delta\theta^h} W_{t\delta}$ in (40). Suppose the incentives to bring in foreign firms via the local content are large where $\theta^h < \theta^h_E$.[11] Then, using proposition 4.6 an increase in θ^h results in a decrease in the local content i.e., $W_{\delta\theta^h} < 0$. A lower local content means lower emissions, but at the same time a reduction in profits and income. In particular, as a result of lower emissions, the government has room to lower (raise) the tax to boost profits and income i.e. $-\varphi'' E^T_t E^T_\delta > 0$

[11] Analogous results are obtained for $\theta^h > \theta^h_E$.

(encourage more foreign firms to enter i.e. $-\varphi' E_{t\delta}^{T} < 0$). Additionally, because a lower local content raises the number of foreign firms the government has additional room to lower the tax to raise profits and income, but also control excessive entry. As a result, the tax is adjusted downwards as long as the incentives to promote profits and income, and control entry are large i.e., $W_{t\theta^h} < 0$ and $W_{t\delta} W_{\delta\theta^h} < 0$, where $W_{t\delta} > 0$. In this case each of the two terms in (40) and (41) is negative. However, if the incentives to bring in foreign firms via the local content are small (i.e., $W_{\delta\theta^h} > 0$), then the tax is adjusted upwards as long as the incentives to bring in foreign firms and tackle emissions via the tax are large i.e., $W_{\delta\theta^h} W_{t\delta} > 0$, $W_{t\theta^h} > 0$. The implication here is that a policy adjustment consisting of laxer (stricter) taxation and laxer (stricter) local content requirements is consistent with the promotion of foreign firms (i.e., FDI) and addressing damages from pollution depending upon whether the government seeks to attract FDI via the local content (taxation).

Proposition 4.7. *Let $\theta^h < \theta_E^h$. Suppose the government attracts FDI via laxer local content requirements. Then, laxer taxation and laxer local content requirements is consistent with the promotion of foreign firms (i.e., FDI) and addressing damages from pollution.*

This section concludes by looking at the case where the government stimulates the entry of foreign firms via higher taxation and a smaller local content i.e., $W_{t\theta^h} > 0$ and $W_{\delta\theta^h} < 0$. With a reduction in the local content profits and income fall, which induces the government to lower the tax. Additionally, the fact that emissions fall with a reduction in the local content affords the government lower taxation. And the entry of foreign firms via the reduction in the local content induces a tax reduction to control for the excessive entry of firms. As a result, the downward adjustment in the tax due to the decrease in the local content (i.e., second term in (40) where $W_{t\delta} > 0$ and $W_{\delta\theta^h} < 0$), is not entirely consistent with the objective of bringing in foreign firms via higher taxation i.e., $W_{t\theta^h} > 0$ in first term in (40). But if the downward adjustment in the tax, due to the local content, is small then both policies can potentially be used to attract foreign firms i.e., higher taxation and lower local content.

5 Fixed number of foreign firms

In order to examine the role of free entry/exit of foreign firms further this section compares results with the case where the number of foreign firms is exogenous. I shall follow the same model structure, but now there is a fixed number of foreign firms, m.

The main result from the analysis is that in the absence of free entry/exit the role of the abatement induced by the tax becomes negligible. Therefore, the effects of the tax and local content on output no longer work via the entry of foreign firms, but exclusively via pollution intensities. For instance, in the case where pollution intensities are equal total emissions fall unambiguously with an increase the local content since the role of abatement vanishes: the presence of abatement incentives opened the possibility for total emissions to rise with the local content (see proposition 3.6).

To see these results, the Cournot-Nash equilibrium is characterized using (11) and (12). In particular, closed-form solutions are given by $q^h = ((m+1)(\alpha - c^h - \theta^h t) - m(\alpha - c^f - \theta^f t)/\beta(m+n+1)$ and $q^f = ((n+1)(\alpha - c^f - \theta^f t) - n(\alpha - c^h - \theta^h t)/\beta(m+n+1)$. Hence, the change in output arising from the emission tax and local content are given by

$$\partial q^h/\partial t = (-\theta^h(m+1) + m\theta^f)/\beta(m+n+1); \quad \partial q^f/\partial t = (-\theta^f(n+1) + n\theta^h)/\beta(m+n+1) \tag{43}$$

$$\partial q^h/\partial \delta = (k^h - k^f)/\beta(m+n+1) > 0; \quad \partial q^f/\partial \delta = -(n+1)(k^h - k^f)/\beta(m+n+1) < 0 \tag{44}$$

Comparing (20) and (21) with (43) indicates that the key difference is the role of the abatement induced by the tax on the free entry and exit of firms (i.e., the last terms in (20) and (21) vanish). The role of pollution intensities is analogous to the case where the number of foreign firms is endogenous: home output falls and foreign output rises as long as the pollution intensity of home firms is sufficiently large. Moreover, comparing the effects of the local content indicates that free entry and exit does not affect the end sign of $\partial q^h/\partial \delta$ and $\partial q^f/\partial \delta$, but the channels whereby the signs are determine vary: the abatement incentives induced by the tax vanish (are key) in the case where the number of firms is fixed (endogenous).

Proposition 5.1. *In the case where the number of foreign firms is exogenous the abatement incentive induced by the tax is negligible. As a result, changes in the tax affect output exclusively via differences in pollution intensities across firms.*

Next, I examine the effects on emissions when the number of foreign firms is exogenous. Using the aforementioned results, differentiation of $E^h = ne^h = n(\theta^h q^h - t)$ and $E^f = me^f = m(\theta^f q^f - t)$ yields

$$dE^h = -n\left[\frac{\theta^h(\theta^h - \theta^f)m + \theta^{h2}}{\beta(m+n+1)} + 1\right]dt + \frac{mn\theta^h(k^h - k^f)}{\beta(m+n+1)}d\delta \tag{45}$$

$$dE^f = -m\left[\frac{\theta^f(\theta^f - \theta^h)n + \theta^{f2}}{\beta(m+n+1)} + 1\right]dt - \frac{m(n+1)\theta^f(k^h - k^f)}{\beta(m+n+1)}d\delta \tag{46}$$

whence the change in total emissions is given by

$$dE^T = -\left[\frac{nm(\theta^h - \theta^f)^2 + (n\theta^{h2} + \theta^{f2}m)}{\beta(m+n+1)} + (m+n)\right]dt + \frac{m(k^h - k^f)}{\beta(m+n+1)}\left[\theta^h n - \theta^f(n+1)\right]d\delta \tag{47}$$

Comparison of (45) and (46) with (27) and (28) indicates that (i) the role of abatement via the emission tax vanishes i.e., the last term in (28) vanishes; and (ii) free entry and exit does not play a role on the effect of the local content on emissions in the home country. Additionally, comparison of (45) and (46) with (22) and (23) indicates that the role of abatement vanishes thus eliminating the incentive of entry/exit of foreign firms (and their impact on emissions) via the abatement induced by the tax i.e., the second term in (22) and the terms with the "t" in (23) vanish. Using proposition 5.1 and combining (45) and (46), indicates that, consistent with Lahiri and Symeonidis (2007, p. 893), total emissions fall unambiguously with a tax increase i.e., regardless of the pair θ^h, θ^f. This is in contrast to the case where the number of firms is endogenous (see proposition 3.1). The entry effect vanishes in the case where the number of firms is fixed.

Furthermore, in the absence of abatement incentives via the tax changes in the local content affect total emissions exclusively via differences in pollution intensities. This is in contrast to the case where the number of foreign firms is endogenous i.e., the last term in (29). As a result, an increase in the local content still raises total emissions if the pollution intensity of home firms is relatively large, but now the condition for total emissions to fall via the local content is less restrictive since issues of abatement via entry/exit of firms vanish. It is noteworthy that in the special case where firms are equally pollution intensive total emissions fall unambiguously with an increase in the local content. This is because with fixed number of firms and identical pollution intensities, an increase in the local content results in a large reduction in foreign output while at the same time the abatement incentive via the tax (which lowers abatement via the exit of firms thereby raising emissions) vanishes.

Proposition 5.2. *Let $\theta^h \neq \theta^f$. In the case where the number of foreign firms is exogenous (i) total emissions fall unambiguously with an increase in the emission tax for any pair of pollution intensity θ^h, θ^f; and (ii) total emissions rise with an increase in the local content if and only if home firms are relatively more pollution intensive.*

Proposition 5.3. *Let $\theta^h = \theta^f = \tilde{\theta}$. In the case where the number of foreign firms is exogenous total emissions fall unambiguously with an increase in the local content i.e., $E^T_\delta < 0$.*

Next, I briefly discuss the adjustment of the tax and local content in the case where the number of foreign firms is exogenous. I rely on the welfare function used previously and equations (40) and (41).[12] In the case of fixed number of firms a tax reduction no longer reduces the entry of foreign firms (and thus output) via abatement incentives, but rather a

[12]The threshold θ^h_E may differ in the case where m is fixed. However, the function $E(\theta^h)$ is strictly concave as in the case of free-entry. Thus, the threshold θ^h_E here is analogous (though not necessarily identical) to that presented in the case of free-entry and proposition 4.2.

tax reduction encourages output of foreign and home firms. Additionally, in the absence of entry and exit of foreign firms, due to the abatement incentives of the tax, an increase in the local content lowers total emissions and so the ability to tackle emissions and at the same time promote output by foreign firms disappears. With these in mind suppose $\theta^h < \theta^h_E$ and let the government promote foreign output via lower taxation; the local content is employed to raise home profits and tackle emissions. Thus, starting at $\theta^h = \theta^f$ an increase in θ^h induces the government to lower the tax to stimulate foreign output (i.e., $W_{t\theta^h} < 0$). At the same time the local content is raised to promote home profits and tackle emissions (i.e., $W_{\delta\theta^h} > 0$). Since the increase in the local content lowers foreign output, the government lowers the tax to offset this effect i.e., $W_{t\delta}W_{\delta\theta^h} < 0$ in (40).[13] Similarly, if the government promotes foreign output via lower local content, then the local content is reduced but the tax is raised to tackle emissions. Therefore, in contrast to proposition 4.7 the tax and local content, absence of free entry/exit effects, move in opposite directions either in the case where taxation or the local content is used to stimulate foreign output. As a result, with fixed number of firms and the incentive to stimulate foreign output via lower local content, a policy adjustment consisting of lower taxation and lower local content requirements may not be consistent with the promotion of FDI and addressing damages from pollution.[14]

Proposition 5.4. *Let $\theta^h < \theta^h_E$. Suppose (i) the number of foreign firms is exogenous and (ii) the government attracts FDI via laxer local content requirements. Then, laxer taxation and laxer local content requirements are less likely to be consistent with the promotion of foreign output (i.e., FDI) and addressing damages from pollution.*

[13] In the case of fixed number of firms at $\theta^h = \theta^f$ $W_{t\delta} = n\pi^h_{t\delta} + I_{t\delta} + E^T_\delta + (t - \varphi')E^T_{t\delta} - \varphi'' E^T_t E^T_\delta$ is always negative since $\pi^h_{t\delta} = 2\beta q^h_t q^h_\delta < 0$, $I_{t\delta} = -m\theta^f/\beta(m+n+1) < 0$, $E^T_{t\delta} = 0$, $E^T_t < 0$, $E^T_\delta < 0$.

[14] However, if the government pursues a policy of lower taxation and local content to promote foreign output, then the sign of (40) is ambiguous and analogous to the case of free-entry. This is because one the one hand the tax is lowered to promote foreign output ($W_{t\theta} < 0$), but on the other the reduction in the local content ($W_{\delta\theta^h} < 0$) raises emissions; thus forcing the government to raise the tax i.e., $W_{t\delta}W_{\delta\theta^h} > 0$.

6 Conclusion

The development of industry (e.g., via FDI) while addressing environmental degradation is at the center of policymaking in many developing countries (OECD 1999). With these policy objectives in mind, this paper develops a Cournot model in the presence of emission taxes and local content requirements where the number of home (foreign) firms is exogenous (endogenous). The analysis indicates that free-entry plays a fundamental role in the recommendation of policy: in the presence of free entry laxer (stricter) policy is consistent with addressing emissions and promoting foreign, less polluting and more efficient firms as long as FDI is promoted via the local content (taxation). This illustrates the potential for stricter policy. In the case where the number of foreign firms is fixed some of the results are reversed.

The analysis of policy reform of the tax and local content suggests that a reduction in emissions is possible, but depends on whether foreign firms are relatively less or more pollution intensive. If domestic firms are relatively more pollution intensive a policy reform consisting of a reduction in the local content and an increase in the tax may lower industry emissions. In a broader sense these results underline the potential role of an emission tax, but also the role of free-entry in mitigating rising emissions.

Crucially, results depend on the assumption that the number of home firms is exogenous. Relaxing this assumption may yield interesting results and it is proposed as a future line of research. For example, if the number of home and foreign firms is endogenous, and foreign firms are relatively less pollution intensive and more efficient, then a tax increase could raise income while addressing emissions by forcing more polluting/less efficient home firms out of the market. Nonetheless, the present work derives results in the case where FDI has the ability to exit/enter the home country's market, while home firms are restricted arguably because they are relatively less efficient.

Furthermore, there are several extensions to the model worth mentioning. First, the inclusion of additional market-based environmental policies may help analyze cases where, for instance, environmental research and development (R&D) subsidies are being used to promote more cost effective and cleaner technologies. Second, some of the results rely, inevitably, on assumptions about functional forms; a clear extension would be to see if results hold in a more general setting. Third, the model could be used to explore cases where home firms are very inefficient or more efficient vis-à-vis foreign firms; in the latter case results presented here could be reversed, but with similar policy implications: attract more efficient firms to tackle emissions and encourage income as well as profits. Fourth, the interaction between pollution intensities and production costs is assumed away in the present model and thus relaxing this assumption can be an interesting extension of the model. For instance, lower production costs for foreign firms may yield higher gross pollution by foreign firms thereby having an impact on the adjustment of policy, particularly if the objective of policymakers is to attract FDI. Fifth, a deeper analysis as to whether policy reform may specifically pave the way for a simultaneous reduction in emissions and increase in income is warranted. This is suggested as a future line of research to shed light on the pollution halo hypothesis. And sixth, an in-depth analysis of the characterization of optimal taxation in the presence of local content requirements is needed, an aspect not delved into in the present analysis.

A Appendix

Consider the following expressions (subscript denote partial derivatives), where an interior solution is assumed so that $\delta \in (0,1)$ and $t > 0$. In particular, using the first-order profit maximization conditions yields

$$\pi^h = \beta(q^h)^2 + t^2/2 - f^h \Rightarrow \pi^h_{\theta^h} = 2\beta q^h q^h_{\theta^h} < 0 \tag{A.1}$$

$$\pi^h_{\theta^h\theta^h} = 2\beta(q^h_{\theta^h})^2 > 0 \tag{A.2}$$

where $q^h_{\theta^h} = -t/\beta < 0$ and $q^h_{\theta^h\theta^h} = 0$. Additionally, as $\theta^h \to \infty$, $\pi^h_{\theta^h} \to 0$; and at $\theta^h = 0$, $\pi^h_{\theta^h} < 0$ due to the non-negativity assumption of q^h, and therefore at $\pi^h > 0$ at $\theta^h = 0$.

Then, using the definition of total emissions $E^T = E^h + E^f$, the definition of $E^h = ne^h$, $E^f = me^f$ in (16) and (17), and equations (13)-(15) gives

$$E^T_{\theta^h} = \beta^{-1} n \left(-(1-\delta)(k^h - k^f) - 2t(\theta^h - \theta^f) + \beta q^f - t^2/q^f\right) \tag{A.3}$$

$$E^T_{\theta^h\theta^h} = -2nt\beta^{-1} < 0 \tag{A.4}$$

Then, differentiation of income $I = k^h n q^h + k^h \delta q^f m$, gives

$$I_{\theta^h} = k^h n q^h_{\theta^h} + k^h \delta Q^f_{\theta^h} = -k^h nt/\beta + k^h nt\delta/\beta = -k^h tn(1-\delta)\beta < 0 \tag{A.5}$$

$$I_{\theta^h\theta^h} = 0 \tag{A.6}$$

where, from equation (15), $Q^f = mq^f$ and so $Q^f_{\theta^h} = tn/\beta$. Then, from the welfare function in (31) one gets

$$W_{\theta^h} = n\pi^h_{\theta^h} + I_{\theta^h} + (t - \varphi')E^T_{\theta^h} \tag{A.7}$$

$$W_{\theta^h\theta^h} = n\pi^h_{\theta^h\theta^h} + (t - \varphi')E^T_{\theta^h\theta^h} - \varphi''(E^T_{\theta^h})^2 \tag{A.8}$$

where $I_{\theta^h\theta^h} = 0$.

Next, the effects of the tax and local content.

$$\pi_t^h = 2\beta q^h q_t^h + t = 2\beta q^h \left(-(\theta^h - \theta^f)/\beta + q_t^f\right) + t \tag{A.9}$$

$$\pi_{t\theta^h}^h = -2q^h + 2t\left(\frac{t}{2\beta q^f} + \frac{(\theta^h - \theta^f)}{\beta}\right) \tag{A.10}$$

$$(1/k^h)I_t = \frac{-n(\theta^h - \theta^f)}{\beta} + nq_t^f + \frac{\delta(\theta^h n - (n+1)\theta^f)}{\beta} - \delta q_t^f(n+1) \tag{A.11}$$

$$I_{t\theta^h} = -nk^h/\beta + \delta nk^h/\beta = -(1-\delta)nk^h/\beta < 0 \tag{A.12}$$

where at $\theta^h = \theta^f$

$$(1/k^h)I_t = \frac{\delta}{\beta}\left(-\theta + t/q^f - t/2q^f\right) - (1-\delta)tn/2\beta q^f < 0 \tag{A.13}$$

where $q_t^f = -t/2\beta q^f$, $-\theta + t/q^f = -(\theta q^f - t)/q^f = -e^f q^f < 0$. From (24) one obtains

$$E_{t\theta^h}^T = \frac{-n(\theta^h - \theta^f)}{\beta} - \frac{t^3}{2\beta q^f} - \frac{5nt}{2\beta q^f} \tag{A.14}$$

where

$$\begin{aligned} n\pi_{t\theta^h}^h + I_{t\theta^h} + E_{\theta^h}^T &= (1-\delta)(k^h - k^f)n/\beta - (1-\delta)nk^h/\beta - nq^f + 2tn(\theta^h - \theta^f)/\beta \\ &= -(1-\delta)nk^f/\beta - nq^f + 2tn(\theta^h - \theta^f)/\beta < 0 \;\; if \;\; \theta^h = \theta^f \end{aligned} \tag{A.15}$$

To elaborate on this point, at $\theta^h = \theta^f$, $E_{t\theta^h}^T < 0$, $I_t < 0$, and

$$n\pi_{t\theta^h}^h = 2n\left((1-\delta)(k^h - k^f)/\beta - q^f\right) + t^2 n/\beta q^f \tag{A.16}$$

$$E_{\theta^h}^T = n\left(-(1-\delta)(k^h - k^f)/\beta + q^f - t^2/\beta q^f\right) \tag{A.17}$$

where I use q^h, evaluated at $\theta^h = \theta^f$, which is given in (14) to obtain the expression of $\pi_{t\theta^h}^h$. Hence, at $\theta^h = \theta^f$

$$n\pi_{t\theta^h}^h + I_{t\theta^h} + E_{\theta^h}^T = -q^f n - k^f n(1-\delta)/\beta < 0 \tag{A.18}$$

Also note that (still under the case where $\theta^h = \theta^f$), if $E_{\theta^h}^T = 0$, then $n\pi_{t\theta^h}^h < 0$. Hence,

$$W_{t\theta^h} = n\pi_{t\theta^h}^h + I_{t\theta^h} + E_{\theta^h}^T + (t - \varphi')E_{t\theta^h}^T - \varphi'' E_t^T E_{\theta^h}^T \tag{A.19}$$

The effects of the local content are as follows

$$\pi^h_\delta = 2\beta q^h q^h_\delta = 2q^h(k^h - k^f) > 0 \tag{A.20}$$

$$\pi^h_{\delta\theta^h} = 2(k^h - k^f)q^h_{\theta^h} = -2(k^h - k^f)t/\beta < 0 \tag{A.21}$$

$$(1/k^h)I_\delta = nq^h_\delta + mq^f + \delta Q^f_\delta = n(k^h - k^f)/\beta + mq^f - \delta(k^h - k^f)(n+1)/\beta \tag{A.22}$$

$$I_{\delta\theta^h} = k^h Q^f_{\theta^h} = k^h tn/\beta > 0 \tag{A.23}$$

$$E_{\delta\theta^h} = (k^h - k^f)n/\beta > 0 \tag{A.24}$$

where $q^h_{\theta^h} = -t/\beta$, $Q^f_{\theta^h} = tn/\beta$. Hence,

$$W_{\delta\theta^h} = n\pi^h_{\delta\theta^h} + I_{\delta\theta^h} + (t - \varphi')E^T_{\delta\theta^h} - \varphi'' E^T_\delta E^T_{\theta^h} \tag{A.25}$$

$$= tn(2k^f - k^h)/\beta + (t - \varphi')E^T_{\delta\theta^h} - \varphi'' E^T_\delta E^T_{\theta^h} \tag{A.26}$$

where $n\pi^h_{\delta\theta^h} + I_{\delta\theta^h} = tn(2k^f - k^h)/\beta$. Equations (A.19) and (A.25) are used in the analysis of policy response i.e., t_{θ^h} and δ_{θ^h}.

The expression for $W_{t\delta}$ is derived next.

$$W_{t\delta} = n\pi^h_{\delta t} + I_{\delta t} + E^T_\delta + (t - \varphi')E^T_{\delta t} - \varphi'' E^T_\delta E^T_t \tag{A.27}$$

where at $\theta^h = \theta^f$

$$n\pi^h_{t\delta} = n\frac{(k^h - k^f)}{\beta}\left(\frac{-t}{2\beta q^f}\right)2\beta < 0 \tag{A.28}$$

$$I_{t\delta} = \beta^{-1}k^h\left(-\theta + (n+1)t/2q^f\right) \tag{A.29}$$

$$E^T_{t\delta} = \beta^{-1}(k^h - k^f)(n+1)\left(1 + t^2/2\beta q^{f2}\right) > 0 \tag{A.30}$$

$$E^T_\delta = \beta^{-1}(k^h - k^f)\left(-\theta + (n+1)t/q^f\right) > 0 \tag{A.31}$$

Next, the derivation of proposition 4.1 is presented. Inspection of the first-order conditions (32) and (33) indicates that the optimal tax may be less or greater than marginal damages depending upon whether the incentive for foreign firms to enter/exit the market via the abatement induced by the tax is strong, the degree of inefficiency of home firms vis-à-vis foreign firms, and the weight the government puts on damages from pollution. Since I am interested in policy changes starting at an equilibrium where $\theta^h = \theta^f$, the characterization of optimal policy focuses on the case where foreign and home firms are equally pollution intensive.

I re-write (32) and (33), respectively, as follows:

$$-(n\pi_t^h + I_t + E) = (t - \varphi')E_t^T \tag{A.32}$$

$$-(n\pi_\delta^h + I_\delta) = (t - \varphi')E_\delta^T \tag{A.33}$$

where by proposition 3.5 $E_t < 0$, but the sign of the rest of the terms is ambiguous.

Consider the condition $k^h < 2k^f$. This condition is consistent with a negative sign for $n\pi_t^h + I_t + E < 0$, as well as a positive sign for $n\pi_\delta^h + I_\delta > 0$. The intuition here is that with not too inefficient home firms (i.e., $k^h < 2k^f$), a decrease (increase) in the tax (local content) increases profits and income. With these in mind and since $E_t^T < 0$, the optimal emission tax is less than marginal damages. As a result, it follows from (A.33) that total emissions and the local content are positively related i.e., $E_\delta^T > 0$.

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Figure 1: Pollution Intensity, Welfare, Total Emissions, Profits and Income: $\theta^h = \theta^f$, $t > 0$, $\delta \in (0, 1)$.