Relational Voluntary Environmental Agreements with Unverifiable Emissions. Supplementary Material

Berardino Cesi[*], Alessio D'Amato[†]

Appendix

Deriving firm level enforcement costs under emission taxation.

This Appendix provides an explicit derivation of the enforcement costs used in the main text under emission taxation, and closely mimics section 4.1. in McEvoy and Stranlund (2010). It is based on standard reasoning according to the well established literature on public enforcement of law (see, among others, Polinsky and Shavell, 2000).

Under emissions taxation, assuming the possibility of firms to underreport the level of actual emissions, each firm chooses actual emissions level (e) and reported emissions level (r) in such a way to maximize expected profits. Those profits depend on gross profits, on tax payment on reported emissions, given, under a unit tax equal to τ, by τr and on enforcement by the regulator. As in McEvoy and Stranlund (2010) we assume that a linear enforcement technology is used by the regulator to achieve full tax related compliance; in other words, the regulator monitors a number $a \leq N$ of firms, and an audit reveals with certainty the true emission level of the audited firm. The amount of per firm monitoring expenses is labelled as x. We label the share of firms that can be monitored by each unit of enforcement expenses as α : this is the (average and) marginal productivity of enforcement expenses. As a result, the assumed (linear) enforcement technology implies that $a = N\alpha x$ firms are audited if x is spent by the regulator, and since audits are random, the probability for any firm to be audited is given by $\rho = \frac{a}{N} = \alpha x$. Further, ϕ is the unit fine on non compliance, and, coherently with the stadard literature on optimal law enforcement (e.g. Polinsky and Shavell, 2000), we also assume that there is an upper limit on the feasible fine for firms detected as non-compliant, labelled as f, i.e. $\phi \leq f$, and

[*]Department of Political Sciences, La Sapienza University of Rome, p.zza Aldo Moro, 5, Rome, Italy

[†]Department of Economics and Finance, Tor Vergata University of Rome and SEEDS, email: damato@economia.uniroma2.it

that the unit fine is not costly. Finally, the degree of non compliance is given by the difference between actual and reported emissions, i.e. $e - r$.

Each firm chooses its level of emissions by solving the following maximization problem:

$$\begin{aligned} & \underset{e,r}{Max}\ \pi(e) - \tau r - \rho\phi\,(e-r) \\ \text{s.t. } e \quad & \geq \quad r \end{aligned}$$

The corresponding Lagrangian function L is given by:

$$L = \ \pi(e) - \tau r - \rho\phi\,(e-r) + \lambda\,(e-r)$$

where λ is the Lagrangian multiplier. Focusing on interior solutions for r and e, the FOCs are:

$$\pi'(e) - \rho\phi + \lambda \quad = \quad 0 \tag{1}$$

$$-\tau + \rho\phi - \lambda \quad = \quad 0 \tag{2}$$

$$e - r \quad \geq \quad 0,\ \lambda \geq 0,\ \lambda\,(e-r) = 0 \tag{3}$$

From (2) and (3) we can conclude that full compliance requires $\rho\phi \geq \tau$. Further, as enforcement effort is costly for the regulator, while the unit fine is not, the latter is set at the maximum possible level, i.e. $\phi = f$, to save on enforcement costs for achieving full compliance, while monitoring is set in such a way that $\rho f = \tau$, i.e. the minimum effort to achieve full compliance. Given the assumed linear technology for monitoring, this implies that x is chosen to satisfy $\alpha x f = \tau$, which implies the following per firm monitoring expenses: $x = \frac{\tau}{\alpha f}$ for full compliance, while the corresponding aggregate expenses are $Nx = \frac{N\tau}{\alpha f}$. Under full compliance, $e = r$, so that, accounting for $\pi'(e) = b - b''e$, from (1) and (2) equilibrium (actual and reported) emissions and profits are given by (3) and (4), respectively, in the main text.

Discussion on results from Corollary 1 and Proposition 4 when $\delta^* < \frac{\tau}{2b-\tau}$.

We here briefly discuss results from Corollary 1 and Proposition 4 when $\frac{1}{\alpha_m f_m} < \frac{b-\tau}{b''} < \frac{S_m}{\alpha_m f_m}$. The **left-hand** inequality is needed for a static VEA to exist as an equilibrium (McEvoy an Stranlund, 2010). Notice that $\frac{S_m}{\alpha_m f_m}$ is decreasing in $\alpha_m f_m$, as:

$$\frac{d\left(\frac{S_m}{\alpha_m f_m}\right)}{d\left(\alpha_m f_m\right)} = N\frac{\left(\alpha_m f_m\right)^2(2b-\tau) + 2(b'')^2 + 2b''\sqrt{(b'')^2 + \alpha_m^2 f_m^2 \tau\,(2b-\tau)}}{\left(\alpha_m f_m\right)^3(\tau - 2b)\sqrt{(b'')^2 + \alpha_m^2 f_m^2 \tau\,(2b-\tau)}} < 0$$

Condition $\frac{b-\tau}{b''} < \frac{S_m}{\alpha_m f_m}$ holds, therefore, when "static" VEA enforcement is relatively ineffective (low productivity α_m or low feasible fine f_m, or both).

When $\frac{S_m}{\alpha_m f_m} > \frac{(b-\tau)}{b''}$, it is easily shown that $\delta^* < \frac{\tau}{2b-\tau}$, where δ^* is the threshold defined in Corollary 1 and in the related proof in the main text. The range of δ such that $S_{\min} < N$ is $\delta \in \left(\frac{2\tau}{2b-\tau}, 1\right)$, therefore we can conclude that whenever $S_{\min} < N$ we also have $\delta > \delta^*$, that implies $S_m > S_{\min}$. This outcome has implications also for Proposition 4. Let:

$$\delta_0 = \frac{\left(\left(\alpha_m f_m + \frac{2b''}{N\tau}\right)\sqrt{\tau\left(2b-\tau\right)}\right)^2}{\left(b'' + \sqrt{(b'')^2 + \left(\alpha_m f_m\right)^2 \tau\left(2b-\tau\right)}\right)^2},$$

We have $\Delta < 0$ (i.e. the static VEA dominates the RVEA in terms of welfare) when $\delta > \delta_0 > \delta^*$. According to the main text in the appendix, in this case, we have that $\delta_0 < (>)1$ if $S_m > (<)\ \widehat{S}_m$, where $\widehat{S}_m = 2 + \frac{2b''}{N(\alpha_m f_m)\tau}$ is defined in Proposition 4. On the other hand, in the range $\delta^* < \frac{\tau}{2b-\tau}$, the condition $\delta_0 > \delta^*$ does not exclude the case $\delta_0 < \frac{\tau}{2b-\tau}$. Indeed, after some manipulation, we can show that $\delta_0 > \frac{\tau}{2b-\tau}$ requires $S_m < N + \frac{2b''}{(\alpha_m f_m)\tau}$, therefore it gives $N + \frac{2b''}{(\alpha_m f_m)\tau} > \widehat{S}_m$. To summarize, we can conclude that

1. If $S_m \le \widehat{S}_m$, we have $\delta_0 \ge 1 > \frac{\tau}{2b-\tau}$, therefore $\Delta > 0$ for any $\delta \in \left(\frac{\tau}{2b-\tau}, 1\right)$.

2. If $S_m > \widehat{S}_m$, we have two subcases:

a. $\widehat{S}_m < S_m < N + \frac{2b''}{(\alpha_m f_m)\tau}$: it gives $\delta_0 \in \left(\frac{\tau}{2b-\tau}, 1\right)$, therefore for $\delta \in \left(\frac{\tau}{2b-\tau}, \delta_0\right)$ we have $\Delta > 0$, while for $\delta \in (\delta_0, 1)$ we have $\Delta < 0$.

b. $S_m > N + \frac{2b''}{(\alpha_m f_m)\tau}$: it gives $\delta_0 < \frac{\tau}{2b-\tau}$, therefore we have $\delta > \delta_0$ and $\Delta < 0$.