Online Appendix

The Political Economy of International Regulatory Cooperation

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Appendix A

In this appendix we prove the claims made in the main text regarding the sufficient conditions for existence and uniqueness of the noncooperative equilibrium. We start with the product standards model.

Claim: In the product standards model, if σ_{ig} does not increase too steeply with the price, then (i) there exists a unique noncooperative equilibrium, and (ii) it satisfies the system (4)+(5).

Proof: We begin by showing that there exists a unique solution to the first-order condition $e_{ig} = \frac{1}{\sigma_{ig}\left(p_g+\phi_{ig}(e_{ig})\right)}\left(\frac{1}{a_{ig}} + \frac{1}{\phi'_{ig}(e_{ig})}\right)$ for any p_g, which must then correspond to the unique maximum of the associated objective function Ω_{ig} given that we assume away corner solutions. Recall that ϕ_{ig} is decreasing and convex, so ϕ'_{ig} is negative and increasing, hence $\frac{1}{\phi'_{ig}}$ is negative and decreasing. Also note that our assumptions imply $\frac{1}{\phi'_{ig}(0)} = 0$ and $\lim_{e_{ig}\to\infty} \frac{1}{\phi'_{ig}(e_{ig})} = -\infty$. Next note that, if σ_{ig} is weakly decreasing in the price, it is weakly increasing in e_{ig} and hence $\frac{1}{\sigma_{ig}\left(p_g+\phi_{ig}(e_{ig})\right)}$ is weakly decreasing in e_{ig}. So in this case the left-hand side of the equation above is a line with slope one and the right-hand side is a decreasing function that starts positive and goes to minus infinity, hence the equation above has a unique solution. Next note that, for the first-order condition to have a unique solution, it suffices to rule out that the right-hand side increase in e_{ig} with slope steeper than or equal to one. A sufficient condition to rule this out is that σ_{ig} not increase too steeply with the price.

Next we show that there exists a unique solution to the system (4)+(5), which must then correspond to the unique noncooperative equilibrium. The argument just above implies that the unilateral optimum given p_g is a well defined function $e_{ig}(p_g)$. Plugging this into the market clearing condition gives $\int_i y_{ig}(p_g) = \int_i d_{ig}\left(p_g + \phi_{ig}\left(e_{ig}(p_g)\right)\right)$. We now show that the consumer price $p_g^c \equiv p_g + \phi_{ig}\left(e_{ig}\left(p_g\right)\right)$ increases weakly with p_g. Given this, the left-hand side is increasing in p_g and the right-hand side is decreasing in p_g, so there is a unique solution.

Differentiating p_g^c yields

$$\frac{dp_g^c}{dp_g} = 1 + \phi'_{ig}\frac{de_{ig}}{dp_g}$$

Differentiating the first order condition (4), it is direct to verify that

$$\frac{de_{ig}}{dp_g} = \frac{\frac{-\sigma'_{ig}}{\sigma_{ig}}e_{ig}}{1 + \frac{\phi''_{ig}}{\sigma_{ig}\phi'^2_{ig}} + \frac{\sigma'_{ig}\phi'_{ig}e_{ig}}{\sigma_{ig}}}$$

and hence

$$\frac{dp_g^c}{dp_g} = \frac{1 + \frac{\phi''_{ig}}{\sigma_{ig}\phi'^2_{ig}}}{1 + \frac{\phi''_{ig}}{\sigma_{ig}\phi'^2_{ig}} + \frac{\sigma'_{ig}\phi'_{ig}e_{ig}}{\sigma_{ig}}}$$

Since $\phi'_{ig} < 0$ and $\phi''_{ig} > 0$ by assumption, $\frac{dp_g^c}{dp_g}$ is positive provided that σ'_{ig} is either nonpositive, or positive but not too large, hence the claim. QED

Next we turn to the analogous claim for the process standards model.

Claim: In the process-standards model, if ε_i does not decrease too steeply with the price, then (i) there exists a unique noncooperative equilibrium, and (ii) it satisfies the system (9)+(10).

Proof: We begin by showing that there exists a unique solution to the first-order condition $z_{ig} = \frac{1}{\varepsilon_{ig}\left(p_g - \varphi_{ig}(z_{ig})\right)}\left(\frac{1+\gamma_{ig}}{b_{ig}} + \frac{1}{\varphi'_{ig}(z_{ig})}\right)$ for any p_g, which must then correspond to the unique maximum of the associated objective function Ω_{ig} given that we rule out corner solutions. Recall that φ'_{ig} is decreasing and convex, so φ'_{ig} is negative and increasing, hence $\frac{1}{\varphi'_{ig}}$ is negative and decreasing. Also note that our assumptions imply $\frac{1}{\varphi'_{ig}(0)} = 0$ and $\lim_{z_{ig}\to\infty}\frac{1}{\varphi'_{ig}(z_{ig})} = -\infty$. Next note that, if ε_{ig} is weakly increasing in the price, it is weakly increasing in z_{ig} and hence $\frac{1}{\varepsilon_{ig}\left(p_g - \varphi_{ig}(z_{ig})\right)}$ is weakly decreasing in z_{ig}. So in this case the left-hand side of the equation above is a line with slope one and the right-hand side is a decreasing function that starts positive and goes to minus infinity, hence the equation above has a unique solution. Next note that, for the first-order condition to have a unique solution, it suffices to rule out that the right-hand side increase in z_{ig} with slope higher than or equal to one. A sufficient condition to rule this out is that ε_{ig} not decrease too steeply with the price.

Next we show that there exists a unique solution to the system (9)+(10), which must then correspond to the unique noncooperative equilibrium. The argument just above implies that the unilateral optimum given p_g is a well defined function $z_{ig}(p_g)$. Plugging this into the market clearing condition gives $\int_i y_{ig}\left(p_g - \varphi_{ig}(z_{ig}(p_g))\right) = \int_i d_{ig}(p_g)$. We now show that the producer price $p_g^p \equiv p_g - \varphi_{ig}(z_{ig}(p_g))$ increases weakly with p_g. Given this, the left-hand side is increasing in p_g and the right-hand side is decreasing in p_g, so there is a unique solution.

Differentiating p_g^p yields

$$\frac{dp_g^p}{dp_g} = 1 - \varphi'_{ig}\frac{dz_{ig}}{dp_g}$$

Differentiating the first order condition (9), it is direct to verify that

$$\frac{dz_{ig}}{dp_g} = \frac{-\frac{\varepsilon'_{ig} z_{ig}}{\varepsilon_{ig}}}{1 + \frac{\varphi''_{ig}}{\varepsilon_{ig}\varphi'^2_{ig}} - \frac{\varepsilon'_{ig}\varphi'_{ig} z_{ig}}{\varepsilon_{ig}}}$$

and hence

$$\frac{dp_g^p}{dp_g} = \frac{1 + \frac{\varphi''_{ig}}{\varepsilon_{ig}\varphi'^2_{ig}}}{1 + \frac{\varphi''_{ig}}{\varepsilon_{ig}\varphi'^2_{ig}} - \frac{\varepsilon'_{ig}\varphi'_{ig} z_{ig}}{\varepsilon_{ig}}}$$

Since $\varphi'_{ig} < 0$ and $\varphi''_{ig} > 0$ by assumption, $\frac{dp_g^c}{dp_g}$ is positive provided that ε'_{ig} is either nonnegative, or negative but not too large, hence the claim. QED

Appendix B

Proof of Proposition 1: We first establish that the best local agreement increases e_{ig} for all i. This follows from two observations. The first one is that Ω_g is increasing in each e_{ig} when evaluated at the noncooperative standards. To see this, differentiate Ω_g to get:

$$\begin{aligned} d\Omega_g &= \int_i \frac{\partial \Omega_{ig}}{\partial e_{ig}} de_{ig} + \frac{\partial \Omega_g}{\partial p_g} dp_g \\ &= \int_i \frac{\partial \Omega_{ig}}{\partial e_{ig}} de_{ig} - \frac{\partial \Omega_g}{\partial p_g} \int_i \frac{\sigma_{ig} d_{ig} \phi'_{ig}}{\int_j (\varepsilon_{jg} y_{jg} + \sigma_{jg} d_{jg})} de_{ig} \end{aligned}$$

where we have differentiated the market clearing condition to write down the expression for dp_g. Note that $\frac{\partial \Omega_{ig}}{\partial e_{ig}} = 0$ for all i at the noncooperative equilibrium and recall from the main text that $\frac{\partial \Omega_g}{\partial p_g} > 0$ at the noncooperative equilibrium. Furthermore $-\int_i \frac{\sigma_{ig} d_{ig} \phi'_{ig}}{\int_j (\varepsilon_{jg} y_{jg} + \sigma_{jg} d_{jg})} de_{ig}$ has the same sign as de_{ig}, hence the claim. The second observation is that, since the gradient of Ω_g at the noncooperative standards $\mathbf{e}_g^N$ is positive for all standards, it follows that the direction of steepest ascent of the objective Ω_g starting from $\mathbf{e}_g^N$ entails loosening all of the standards.

Next we show that this local result holds globally if (i) demand semi-elasticities σ_{ig} do not vary too much with the consumer price, or (ii) countries are sufficiently close to symmetric, or (iii) the political parameters γ_{ig} are sufficiently large.

(i) Suppose first that the demand semi-elasticities σ_{ig} are constant. It is then immediate from equations (4) and (6) that $e_{ig}^{A} > e_{ig}^{N}$. A continuity argument can then be used to show that the result continues to hold if the demand semi-elasticities σ_{ig} are sufficiently close to constant.

(ii) Suppose countries are symmetric. Under our assumptions $\Omega_g(\mathbf{e}_g, p_g(\mathbf{e}_g))$ has a unique peak, which is symmetric. Letting $\Omega_g(e_g, p_g(e_g))$ denote the joint government payoff given a common standard e_g, also this function clearly has a single peak, which we denote e_g^A.

We know from the local argument in the main text that $\frac{d\Omega_g}{de_g}|_{NE} > 0$. Given that $\Omega_g(e_g, p(e_g))$ is single-peaked, it follows immediately that $e_g^A > e_g^N$, where e_g^N is the symmetric noncooperative standard. A continuity argument can then be used to extend this result to the case where countries are sufficiently close to symmetric.

(iii) We first argue that, if $\gamma_g \to \infty$ for all i, then $e_{ig}^A \to \infty$ for all i. This follows from the fact that, in the limit as $\gamma_g \to \infty$ for all i, the cooperative standards must maximize $\int_i \nu_{ig}\pi_{ig}(p_g)$, and this implies $e_{ig}^A \to \infty$ for all i. More concretely, suppose by contradiction that, as $\gamma_g \to \infty$ for all i, the optimal standards e_{ig}^A converge to some finite levels $\bar{e}_{ig}$ for a positive measure of countries. Then clearly there exist large enough values of γ_g such that the optimal standards for these countries are looser than $\bar{e}_{ig}$.

Finally, recalling that e_{ig}^N is independent of γ_g, we can conclude that the agreement loosens all standards if γ_g is sufficiently large. QED

Proof of Proposition 2: Before proving the more general result stated in Proposition 2, we focus on the case of symmetric countries and prove the stronger result illustrated in Figure 1.

(i) We show that, if countries are symmetric, there exists a cutoff value $\bar{\gamma}_g$ such that $\Delta_g > 0$ for $\gamma_g < \bar{\gamma}_g$ and $\Delta_g < 0$ for $\gamma_g > \bar{\gamma}_g$.

We begin by characterizing e_g^N, e_g^W, and e_g^A as functions of γ_g. It is immediate that $\frac{de_g^N}{d\gamma_g} = 0$, $\frac{de_g^W}{d\gamma_g} = 0$, and that $e_g^A = e_g^W$ for $\gamma_g = 0$.

Next we show that e_g^A is increasing in γ_g. Let $\tilde{\Omega}_g(e_g, \gamma_g) \equiv \Omega_g\left(e_g, p(e_g), \gamma_g\right)$ (with a slight abuse of notation we have emphasized the dependence of Ω_g on γ_g), and note that $\frac{d^2\tilde{\Omega}_g}{de_g d\gamma_g} = \frac{y_g d_g' \phi_g'}{y_g' - d_g'} > 0$. Thus $\tilde{\Omega}_g$ is supermodular in e_g and γ_g, and hence by standard supermodularity arguments it follows that $\frac{de_g^A}{d\gamma_g} > 0$.

We now turn to characterizing W_g^N and W_g^A as functions of γ_g. Note that $\frac{de_g^N}{d\gamma_g} = 0$ implies $\frac{dW_g^N}{d\gamma_g} = 0$ and $\frac{de_g^A}{d\gamma_g} > 0$ implies $\frac{dW_g^A}{d\gamma_g} < 0$, since e_g^A maximizes welfare when $\gamma_g = 0$ and global welfare is single-peaked in e_g by assumption. It follows that $\frac{d\Delta_g}{d\gamma_g} < 0$.

The final step is to show that $\Delta_g < 0$ for sufficiently large γ_g. Recalling from the proof of the previous proposition that $\lim_{\gamma_g \to \infty} e_{ig}^A = \infty$, it is clear that $\lim_{\gamma_g \to \infty} W_g^A = -\infty$, so there must exist some $\bar{\gamma}_g$ such that $\Delta_g < 0$ for $\gamma_g > \bar{\gamma}_g$.

(ii) We now allow for asymmetric countries. Recall that we define $\gamma_{ig} = \gamma_g \nu_{ig}$ and vary γ_g. With asymmetric countries, it is still trivially true that $\Delta_g > 0$ for $\gamma_g = 0$, and thus also for sufficiently low γ_g. Moreover, it is also still true that $\lim_{\gamma_g \to \infty} e_{ig}^A = \infty$ for all i and thus $\Delta_g < 0$ for sufficiently large γ_g. QED

Proof of Proposition 3: In the main text we established that $\frac{\partial \Omega_g}{\partial p_g}|_{NE}$ is positive if γ_g is large enough and negative if γ_g is small enough. Using a similar argument as in the proof of Proposition 1, it is easy to argue that the best local agreement tightens all process standards if γ_g is large enough and loosens all process standards if γ_g is small enough.

Now we show that this local result holds globally under the conditions stated in Proposition 3.

(i_a) Suppose countries are symmetric. Under our assumptions, $\Omega_g(\mathbf{z}_g, p_g(\mathbf{z}_g))$ has a unique maximum, which entails the same standard for all countries. Let z_g^A denote the symmetric cooperative standard. Let $\Omega_g(z_g, p_g(z_g))$ denote the joint government payoff given a common standard z_g. Also this function clearly has a single peak at z_g^A.

We know from the local argument in the main text that $\frac{d\Omega_g}{dz_g}|_{NE} > 0$ for small enough γ_g. Given that $\Omega_g(z_g, p(z_g))$ is single-peaked, it follows immediately that $z_g^A > z_g^N$ for small enough γ_g, where z_g^N is the symmetric noncooperative standard. A continuity argument can then be used to extend this result to the case where countries are sufficiently close to symmetric.

(i_b) We now argue that the globally optimal agreement loosens all standards for small enough γ_g, as long as the semi-elasticities ε_{ig} are sufficiently close to constant.

Suppose first that $\gamma_g = 0$ and the supply semi-elasticities ε_{ig} are constant. Note that in this case $\lambda_g < 0$. It is then immediate from comparing equations (9) and (11) that $z_g^A > z_g^N$. A continuity argument can then be used to show that this result continues to hold if γ_g is sufficiently close to zero and the supply semi-elasticities ε_{ig} are sufficiently close to constant.

(ii) We now argue that the globally optimal agreement tightens all standards if γ_g is large enough. In fact we will show a stronger result, namely that $z_{ig}^N - z_{ig}^A \to \infty$ as $\gamma_g \to \infty$ for all (except possibly a zero measure of) countries, a result that we will use in the next proof below.

First recall from equation (11) that $z_{ig}^A = \frac{1}{\varepsilon_{ig}} \left(\frac{1+\gamma_{ig}}{b_{ig}} + \frac{1}{\varphi'_{ig}\left(z_{ig}^A\right)} \right) - \frac{\lambda_g}{b_{ig}}$, where the multiplier is given by $\lambda_g = \frac{\int_i y_{ig}\left(\gamma_{ig} - b_{ig} z_{ig}^A \varepsilon_{ig}\right)}{\int_i \varepsilon_{ig} y_{ig} + \int_i \sigma_{ig} d_{ig}}$. Substituting the first equation into the second and rearranging yields

$$\lambda_g = -\frac{\int_i y_{ig} \left(1 + \frac{b_{ig}}{\varphi'_{ig}\left(z_{ig}^A\right)} \right)}{\int_i \sigma_{ig} d_{ig}}$$

Second, note that $\lim_{\gamma_g \to \infty} z_{ig}^N = \infty$. To see this, recall from (9) that $z_{ig}^N = \frac{1}{\varepsilon_{ig}} \left(\frac{1+\gamma_{ig}}{b_{ig}} + \frac{1}{\varphi'_{ig}(z_{ig}^N)} \right)$. Given the assumption that ε_{ig} is bounded, the right hand side of the above expression goes to infinity as $\gamma_{ig} \to \infty$, unless $\frac{1}{\varphi'_{ig}(z_{ig}^N)} \to -\infty$. But given our assumptions on the abatement cost function, the latter can happen only if $z_{ig}^N \to \infty$, thus the claim follows.

Now suppose by contradiction that $z_{ig}^N - z_{ig}^A$ stays bounded (or goes to $-\infty$) for a positive measure of countries, say group A. Then $\lim_{\gamma_g \to \infty} z_{ig}^A = \infty$ for group A, since $\lim_{\gamma_g \to \infty} z_{ig}^N = \infty$. This implies that $\varphi'_{ig}\left(z_{ig}^A\right) \to 0^-$ for group A. Also, for these countries y_{ig} is clearly bounded away from zero, so $y_{ig} \left(1 + \frac{b_{ig}}{\varphi'_{ig}\left(z_{ig}^A\right)} \right) \to -\infty$ for group A. Furthermore, recalling the assumption that σ_{ig} is bounded, $\int_i \sigma_{ig} d_{ig}$ stays bounded, and therefore $\lim_{\gamma_g \to \infty} \lambda_g = \infty$. Keeping in mind that λ_g is the same for all countries, and using the formulas for the noncooperative standards (9) and cooperative standards (11), it is easy to see that $z_{ig}^N - z_{ig}^A$ must then go to infinity for all countries, thus contradicting the premise.

We can conclude that $z_{ig}^N - z_{ig}^A \to \infty$ as $\gamma_g \to \infty$ for all (except possibly a zero measure of) countries. QED

Proof of Proposition 4: We separate this proof into two parts. First, we focus on the case with symmetric countries and constant semi-elasticities and prove the result illustrated in Figure 2. Then we turn to the general case and prove the result stated in proposition 4.

(i) We first focus on the case of symmetric countries and constant semi-elasticities and prove the result illustrated in Figure 2, and namely that there exist critical levels $\gamma_g^L < \gamma_g^H$ such that the agreement increases welfare if $\gamma_g < \gamma_g^L$, decreases welfare if $\gamma_g \in \left(\gamma_g^L, \gamma_g^H\right)$, and increases welfare again if $\gamma_g > \gamma_g^H$.

We begin by showing that the schedules $z_g^N(\gamma_g)$ and $z_g^A(\gamma_g)$ are both increasing, and that

$z_g^N(\gamma_g)$ crosses $z_g^A(\gamma_g)$ only once and from below. Differentiating equations (9) and (11) yields

$$\begin{aligned}\frac{dz_g^N}{d\gamma_g} &= \frac{1}{\varepsilon_g b_g}\left(1+\frac{\varphi_g''(z_g^N)}{\varepsilon_g\varphi_g'^2(z_g^N)}\right)^{-1}\\ \frac{dz_g^A}{d\gamma_g} &= \frac{1}{\varepsilon_g b_g}\left(1+\frac{\varphi_g''(z_g^A)}{\varepsilon_g\varphi_g'^2(z_g^A)}+\frac{\varphi_g''(z_g^A)}{\sigma_g\varphi_g'^2(z_g^A)}\right)^{-1}\end{aligned}$$

where we have used the fact that $y_g = d_g$ under symmetry. Since $\varphi_g'' > 0$, it follows that $\frac{dz_g^N}{d\gamma_g} > 0$ and $\frac{dz_g^A}{d\gamma_g} > 0$. Next recall from the previous proposition that $z_g^N(0) < z_g^A(0)$ and $z_g^N(\infty) > z_g^A(\infty)$, so $z_g^N(\gamma_g)$ must cross $z_g^A(\gamma_g)$ at least once and from below. Finally note that, at any point where the two schedules cross, it must be $z_g^A = z_g^N$, and hence using the expressions above $\frac{dz_g^N}{d\gamma_g} > \frac{dz_g^A}{d\gamma_g}$. This immediately implies that $z_g^N(\gamma_g)$ crosses $z_g^A(\gamma_g)$ only once and from below.

We are now ready to show that there exist cutoffs $\gamma_g^L < \gamma_g^H$ such that $\Delta_g > 0$ if $\gamma_g < \gamma_g^L$ or $\gamma_g > \gamma_g^H$ and $\Delta_g < 0$ if $\gamma_g \in \left(\gamma_g^L, \gamma_g^H\right)$.

With reference to Figure 2, let γ_g^M denote the value of γ_g such that the noncooperative standard is efficient, that is $z_g^N = z_g^W$, and let γ_g^H denote the value of γ_g such that $z_g^N = z_g^A$.

Clearly, we have $\Delta_g > 0$ at $\gamma_g = 0$, $\Delta_g < 0$ at $\gamma_g = \gamma_g^M$, and $\Delta_g = 0$ at $\gamma_g = \gamma_g^H$. Note also that W_g is increasing in z_g for all $z_g < z_g^W$ and decreasing in z_g for all $z_g > z_g^W$, given that z_g^W maximizes W_g and W_g is single-peaked in z_g.

For all $\gamma_g \in \left[0, \gamma_g^M\right)$, clearly $\frac{dW_g^A}{d\gamma_g} < 0$ and $\frac{dW_g^N}{d\gamma_g} > 0$, and hence $\frac{d\Delta_g}{d\gamma_g} < 0$, so there exists a critical value γ_g^L between 0 and γ_g^M such that $\Delta_g > 0$ for $\gamma_g \in \left[0, \gamma_g^L\right)$ and $\Delta_g < 0$ for $\gamma_g \in \left(\gamma_g^L, \gamma_g^M\right]$. Moreover, it is clear that $\Delta_g < 0$ for all $\gamma_g \in \left[\gamma_g^M, \gamma_g^H\right)$ given that, when γ_g is in this range, $z_g^W \leq z_g^N \leq z_g^A$ and W_g is increasing in z_g for all $z_g < z_g^W$. And finally, $\Delta_g > 0$ for all $\gamma_g > \gamma_g^H$ given that, when γ_g is above this threshold, $z_g^W \leq z_g^A \leq z_g^N$ and W_g is decreasing in z_g for all $z_g > z_g^W$.

(ii) We now turn to the general case allowing for asymmetric countries. Recall our scaling convention $\gamma_{ig} = \gamma_g \nu_{ig}$ and consider the limit cases $\gamma_g = 0$ and $\gamma_g \to \infty$. It is still (trivially) true that $\Delta_g > 0$ for $\gamma_g = 0$ and thus also for sufficiently low γ_g. What remains to be shown is that cooperation on process standards increases global welfare if γ_g is sufficiently high.

From the expression for welfare, it follows immediately that

$$\lim_{\gamma_g\to\infty} W_g^N = \lim_{\gamma_g\to\infty}\int_i \left[\pi_{ig}\left(p_g^N - \varphi_{ig}\left(z_{ig}^N\right)\right) + S_{ig}\left(p_g^N\right) - b_{ig} z_{ig}^N y_{ig}\left(p_g^N - \varphi_{ig}\left(z_{ig}^N\right)\right)\right]$$

Recall from the proof of Proposition 3 that $\lim_{\gamma_g\to\infty} z_{ig}^N = \infty$ for all i. Note that therefore

$\lim_{\gamma_g \to \infty} W_g^N = -\infty$, since $\pi_{ig}\left(p_g^N - \varphi_{ig}\left(z_{ig}^N\right)\right)$, $S_{ig}\left(p_g^N\right)$, and $y_{ig}\left(p_g^N - \varphi_{ig}\left(z_{ig}^N\right)\right)$ converge to some finite levels as $\gamma_g \to \infty$.

Similarly,

$$\lim_{\gamma_g \to \infty} W_g^A = \lim_{\gamma_g \to \infty} \int_i \left[\pi_{ig}\left(p_g^A - \varphi_{ig}\left(z_{ig}^A\right)\right) + S_{ig}\left(p_g^A\right) - b_{ig} z_{ig}^A y_{ig}\left(p_g^A - \varphi_{ig}\left(z_{ig}^A\right)\right)\right]$$

For each country, we need to consider two possibilities: z_{ig}^A may go to infinity, or it may stay bounded (possibly at the prohibitive level). The latter possibility cannot be ruled out because there may be a group of countries with much lower ν_{ig} than other countries, and "counter-lobbying" by more powerful countries may push the standards in this group to get tighter. Letting $\mathcal{F}_g^B$ denote the (possibly empty) subset of countries for which z_{ig}^A stays bounded as $\gamma_g \to \infty$, we can write

$$\begin{aligned}
\lim_{\gamma_g \to \infty} \Delta_g \equiv & \lim_{\gamma_g \to \infty} \left(W_g^A - W_g^N\right) \\
= & \lim_{\gamma_g \to \infty} \int_{i \in \mathcal{F}_g^B} \left(W_{ig}^A - W_{ig}^N\right) \\
& + \lim_{\gamma_g \to \infty} \int_{i \notin \mathcal{F}_g^B} \left[\left(\pi_{ig}\left(p_g^A - \varphi_{ig}(z_{ig}^A)\right) + S_{ig}(p_g^A)\right) - \left(\pi_{ig}\left(p_g^N - \varphi_{ig}(z_{ig}^N)\right) + S_{ig}(p_g^N)\right)\right] \\
& + \lim_{\gamma_g \to \infty} \int_{i \notin \mathcal{F}_g^B} \left[b_{ig} z_{ig}^N y_{ig}\left(p_g^N - \varphi_{ig}(z_{ig}^N)\right) - b_{ig} z_{ig}^A y_{ig}\left(p_g^A - \varphi_{ig}(z_{ig}^A)\right)\right]
\end{aligned}$$

The first term of the sum above goes to ∞, since z_{ig}^A stays bounded for $i \in \mathcal{F}_g^B$ and hence W_{ig}^A also stays bounded for these countries, while $\lim_{\gamma_g \to \infty} W_{ig}^N = -\infty$. The second term stays bounded, since clearly p_g^A and p_g^N both stay bounded. The third term goes to ∞ since $y_{ig}\left(p_g^N - \varphi_{ig}\left(z_{ig}^N\right)\right)$ and $y_{ig}\left(p_g^A - \varphi_{ig}\left(z_{ig}^A\right)\right)$ stay bounded and $\lim_{\gamma_g \to \infty}\left(z_{ig}^N - z_{ig}^A\right) = \infty$ as established in the proof of Proposition 3. We can conclude that $\lim_{\gamma_g \to \infty} \Delta_g = \infty$. QED.

Appendix C

We start with the model of product standards. We first prove the claims made in the main text about the positive effects of the globally optimal agreement:

Proposition 1': The equilibrium agreement loosens all product standards, provided that (i) countries are not too asymmetric, or (ii) the political parameters γ_{ig} are sufficiently large.

Proof: Result (i) can be established following similar steps as in the proof of Proposition 1(i). The first step is to show that the best local agreement loosens standards. Next, if countries are symmetric the problem is effectively one-dimensional, and using the assumption that the objective function is single-peaked one can show that the local result holds globally. And finally, the result can be extended by continuity if countries are sufficiently close to symmetric.

Next we focus on result (ii). As usual, we let $\gamma_{ig} = \gamma_g \nu_{ig}$ and consider the limit as $\gamma_g \to \infty$. It is easy to check that the first-order conditions associated with the noncooperative and cooperative problems can be written as $f_{ig}(e_{ig}, \mathbf{e}_{-ig}) + \lambda_g^N(e_{ig}, \mathbf{e}_{-ig})\, g_{ig}(e_{ig}, \mathbf{e}_{-ig}) = 0$ and $f_{ig}(e_{ig}, \mathbf{e}_{-ig}) + \lambda_g^A(e_{ig}, \mathbf{e}_{-ig})\, g_{ig}(e_{ig}, \mathbf{e}_{-ig}) = 0$, where $f_{ig}(e_{ig}, \mathbf{e}_{-ig}) \equiv -d_{ig}\phi'_{ig} - a_{ig}d_{ig}\left(1 - e_{ig}\sigma_{ig}\phi'_{ig}\right)$ and $g_{ig}(e_{ig}, \mathbf{e}_{-ig}) \equiv -d_{ig}\sigma_{ig}\phi'_{ig}$, and the arguments $(e_{ig}, \mathbf{e}_{-ig})$ emphasize that all endogenous variables in general depend on all the standards. Note that, as we increase e_{ig}, the left-hand side has to cross zero once and from above in both cases, given our assumption that the noncooperative and cooperative problems each have a unique interior solution.

We first establish that $\lim_{\gamma_g \to \infty} e_{ig}^N = \infty$ and $\lim_{\gamma_g \to \infty} e_{ig}^A = \infty$ for all i. This follows immediately from the above first-order conditions combined with the fact that $\lambda_g^N(e_{ig}, \mathbf{e}_{-ig})$ and $\lambda_g^A(e_{ig}, \mathbf{e}_{-ig})$ are linearly increasing in γ_g for given standards $(e_{ig}, \mathbf{e}_{-ig})$, as is easy to see from equations (13) and (14).

We now establish that $\lim_{\gamma_g \to \infty}\left(e_{ig}^A - e_{ig}^N\right) > 0$ for all i. This follows from two observations. First, $\lambda_g^A(e_{ig}, \mathbf{e}_{-ig}) - \lambda_{ig}^N(e_{ig}, \mathbf{e}_{-ig}) \to \infty$ for any $(e_{ig}, \mathbf{e}_{-ig})$ as $\gamma_g \to \infty$, as is easy to establish by combining the expressions for λ_{ig}^N and λ_g^A from equations (13) and (14) to $\lambda_g^A(e_{ig}, \mathbf{e}_{-ig}) - \lambda_{ig}^N(e_{ig}, \mathbf{e}_{-ig}) = \frac{\sum_{j \neq i}\left(\gamma_{jg}y_{jg} + a_{jg}e_{jg}\sigma_{jg}d_{jg}\right) + m_{ig}}{\sum_j (\varepsilon_{jg}y_{jg} + \sigma_{jg}d_{jg})}$. Second, as γ_g becomes large and thus e_{ig}^N and e_{ig}^A become large, the standards of countries $j \neq i$ only have a negligible impact on the first-order conditions for country i, so we can write them as $f_{ig}(e_{ig}) + \lambda_g^N(e_{ig})\, g_{ig}(e_{ig}) = 0$ and $f_{ig}(e_{ig}) + \lambda_g^A(e_{ig})\, g_{ig}(e_{ig}) = 0$. To see this note that, as e_{ig}^N and e_{ig}^A become large, the equilibrium price and thus d_{ig} and y_{ig} converge to their unregulated levels, and recall the assumption that σ_{ig} and ε_{ig} are bounded above and bounded away from zero. These two observations together immediately imply the result. QED

Next we prove the claim made in the main text regarding the welfare impact of the equilibrium agreement:

Proposition 2': Suppose all political parameters are scaled by a factor γ_g. Cooperation on product standards increases global welfare if γ_g is sufficiently low, and decreases global welfare if γ_g is sufficiently high.

Proof: It is immediate that cooperation on product standards increases global welfare if $\gamma_g = 0$ and hence also if γ_g is sufficiently low. We now show that the agreement decreases global welfare if γ_g is sufficiently high.

From the expression for welfare, it follows immediately that

$$\begin{aligned}
W_g^A - W_g^N &= \sum_i \left[\pi_{ig}\left(p_g^A\right) - \pi_{ig}\left(p_g^N\right)\right] \\
&\quad + \sum_i \left[S_{ig}\left(p_g^A + \phi_{ig}\left(e_{ig}^A\right)\right) - S_{ig}\left(p_g^N + \phi_{ig}\left(e_{ig}^N\right)\right)\right] \\
&\quad - \sum_i a_{ig}\left[e_{ig}^A d_{ig}\left(p_g^A + \phi_{ig}\left(e_{ig}^A\right)\right) - e_{ig}^N d_{ig}\left(p_g^N + \phi_{ig}\left(e_{ig}^N\right)\right)\right]
\end{aligned}$$

Recalling from the previous proof that $\lim_{\gamma_g \to \infty} e_{ig}^N = \infty$ and $\lim_{\gamma_g \to \infty} e_{ig}^A = \infty$, this implies

$$\begin{aligned}
\lim_{\gamma_g \to \infty}\left(W_g^A - W_g^N\right) &= \sum_i \left[\pi_{ig}\left(\tilde{p}_g\right) - \pi_{ig}\left(\tilde{p}_g\right)\right] \\
&\quad + \sum_i \left[S_{ig}\left(\tilde{p}_g\right) - S_{ig}\left(\tilde{p}_g\right)\right] \\
&\quad - \sum_i a_{ig} d_{ig}\left(\tilde{p}_g\right)\left(e_{ig}^A - e_{ig}^N\right) \\
&= -\sum_i a_{ig} d_{ig}\left(\tilde{p}_g\right)\left(e_{ig}^A - e_{ig}^N\right),
\end{aligned}$$

where $\tilde{p}_g$ is the unregulated world price, i.e. the solution to $\sum_i y_{ig}\left(p_g\right) = \sum_i d_{ig}\left(p_g\right)$. Hence, $\lim_{\gamma_g \to \infty}\left(W_g^A - W_g^N\right) < 0$ if $e_{ig}^A > e_{ig}^N$ for all i, which is true for sufficiently large γ_g, as shown above. QED

We now turn to the model of process standards. We start by proving the claims made in the main text about the positive effects of the globally optimal agreement:

Proposition 3': (i) The equilibrium agreement loosens all process standards for sufficiently small γ_g, provided countries are sufficiently symmetric; (ii) The equilibrium agreement tightens all process standards for sufficiently large γ_g, as long as ν_{ig} and ε_{ig} are not too dissimilar across countries.

Proof: Result (i) can be established following similar steps as in the proof of Proposition 3, part (i_a). We therefore focus on result (ii). As usual, we decompose $\gamma_{ig} = \gamma_g \nu_{ig}$ and consider the limit $\gamma_g \to \infty$.

It is easy to check that the first-order conditions associated with the noncooperative and cooperative problems can be written as $f_{ig}\left(z_{ig}, \mathbf{z}_{-ig}\right) + \left(\gamma_{ig} - \lambda_{ig}^N\left(z_{ig}, \mathbf{z}_{-ig}\right)\varepsilon_{ig}\right) g_{ig}\left(z_{ig}, \mathbf{z}_{-ig}\right) = 0$ and $f_{ig}\left(z_{ig}, \mathbf{z}_{-ig}\right) + \left(\gamma_{ig} - \lambda_g^A\left(z_{ig}, \mathbf{z}_{-ig}\right)\varepsilon_{ig}\right) g_{ig}\left(z_{ig}, \mathbf{z}_{-ig}\right) = 0$, where $f_{ig}\left(z_{ig}, \mathbf{z}_{-ig}\right) \equiv -y_{ig}\varphi_{ig}' - b_{ig} y_{ig}\left(1 - z_{ig}\varepsilon_{ig}\varphi_{ig}'\right)$, $g_{ig}\left(z_{ig}, \mathbf{z}_{-ig}\right) \equiv -y_{ig}\varphi_{ig}'$, and the arguments $\left(z_{ig}, \mathbf{z}_{-ig}\right)$ emphasize that all endogenous variables in general depend on all the standards. Note that, as we increase z_{ig}, the left-hand side has to cross zero once and from above in both cases, given our assumption that the noncooperative and cooperative problems each have a unique interior solution.

We first establish that $\lim_{\gamma_g \to \infty} z_{ig}^N = \infty$ for all i. This follows from the above first-order condition for noncooperative standards combined with the fact that the expression for $\gamma_{ig} - \lambda_{ig}^N (z_{ig}, \mathbf{z}_{-ig}) \varepsilon_{ig}$ is linearly increasing in γ_g for given standards $(z_{ig}, \mathbf{z}_{-ig})$. To see this, note that we can use equation (15) to rewrite $\gamma_{ig} - \lambda_{ig}^N \varepsilon_{ig} = \gamma_{ig} \frac{\sum_{j \neq i} \varepsilon_{jg} y_{jg} + \sum_j \sigma_{jg} d_{jg}}{\sum_j (\varepsilon_{jg} y_{jg} + \sigma_{jg} d_{jg})} + \frac{b_{ig} z_{ig} \varepsilon_{ig} y_{ig} + m_{ig}}{\sum_j (\varepsilon_{jg} y_{jg} + \sigma_{jg} d_{jg})} \varepsilon_{ig}$.

We next show that $\lim_{\gamma_g \to \infty} z_{ig}^A = \infty$ for all i provided that γ_{ig} and ε_{ig} are not too dissimilar across countries. This follows from the above first-order condition for cooperative standards combined with the fact that the expression for $\gamma_{ig} - \lambda_g^A (z_{ig}, \mathbf{z}_{-ig}) \varepsilon_{ig}$ is linearly increasing in γ_g for given standards $(z_{ig}, \mathbf{z}_{-ig})$. To see this, note that we can use equation (16) to rewrite $\gamma_{ig} - \lambda_g^A \varepsilon_{ig} = \gamma_g \frac{\sum_j \sigma_{jg} d_{jg}}{\sum_j (\varepsilon_g y_{jg} + \sigma_{jg} d_{jg})} + \frac{\sum_j b_{jg} z_{jg} \varepsilon_g y_{jg}}{\sum_j (\varepsilon_g y_{jg} + \sigma_{jg} d_{jg})} \varepsilon_g$, upon imposing $\gamma_{ig} = \gamma_g$ and $\varepsilon_{ig} = \varepsilon_g$ for all i.

We now establish that $\lim_{\gamma_g \to \infty} \left(z_{ig}^N - z_{ig}^A \right) > 0$ for all i. This follows from two observations. First, $\lambda_g^A (z_{ig}, \mathbf{z}_{-ig}) - \lambda_{ig}^N (z_{ig}, \mathbf{z}_{-ig}) \to \infty$ for any $(z_{ig}, \mathbf{z}_{-ig})$ as $\gamma_g \to \infty$, as is easy to establish by combining the expressions for λ_{ig}^N and λ_g^A from equations (15) and (16) to $\lambda_g^A (z_{ig}, \mathbf{z}_{-ig}) - \lambda_{ig}^N (z_{ig}, \mathbf{z}_{-ig}) = \frac{\sum_{j \neq i} y_{jg} \left(\gamma_{jg} - b_{jg} z_{jg} \varepsilon_{jg} \right) + m_{ig}}{\sum_j (\varepsilon_{jg} y_{jg} + \sigma_{jg} d_{jg})}$. Second, as γ_g becomes large and thus z_{ig}^N and z_{ig}^A become large, the standards of all countries $j \neq i$ only have a negligible impact on the first-order conditions of country i so that we can write them as $f_{ig}(z_{ig}) + \left(\gamma_{ig} - \lambda_{ig}^N (z_{ig}) \varepsilon_{ig} \right) g_{ig}(z_{ig}) = 0$ and $f_{ig}(z_{ig}) + \left(\gamma_{ig} - \lambda_{ig}^A (z_{ig}) \varepsilon_{ig} \right) g_{ig}(z_{ig}) = 0$. To see this, note that the equilibrium price and thus d_{ig} and y_{ig} converge to their unregulated levels as $z_{ig}^A \to \infty$ and $z_{ig}^N \to \infty$, and recall the assumption that σ_{ig} and ε_{ig} are bounded above and away from zero. These two observations together immediately imply the result. QED

Finally, we prove the claim made in the main text regarding the welfare impact of the equilibrium agreement:

Proposition 4': Cooperation on process standards increases global welfare if γ_g is sufficiently low. It also increases global welfare if γ_g is sufficiently high, as long as ν_{ig} and ε_{ig} are not too dissimilar across countries.

Proof: It is immediate that the agreement increases global welfare if $\gamma_g = 0$ and hence also if γ_g is sufficiently low. We now show that the agreement increases global welfare also if γ_g is sufficiently high, as long as ν_{ig} and ε_{ig} are not too dissimilar across countries.

From the expression for welfare, it follows immediately that

$$\begin{aligned} W_g^A - W_g^N &= \sum_i \left[\pi_{ig}\left(p_g^A - \varphi_{ig}\left(z_{ig}^A\right)\right) - \pi_{ig}\left(p_g^N - \varphi_{ig}\left(z_{ig}^N\right)\right)\right] \\ &+ \sum_i \left[S_{ig}\left(p_g^A\right) - S_{ig}\left(p_g^N\right)\right] \\ &- \sum_i b_{ig}\left[z_{ig}^A y_{ig}\left(p_g^A - \varphi_{ig}\left(z_{ig}^A\right)\right) - z_{ig}^N y_{ig}\left(p_g^N - \varphi_{ig}\left(z_{ig}^N\right)\right)\right] \end{aligned}$$

Recalling from the previous proof that $\lim_{\gamma_g \to \infty} z_{ig}^N = \infty$ and $\lim_{\gamma_g \to \infty} z_{ig}^A = \infty$ as long as the political parameters γ_{ig} and the supply semi-elasticities ε_{ig} are not too dissimilar across countries, this implies

$$\begin{aligned} \lim_{\gamma_g \to \infty} \left(W_g^A - W_g^N\right) &= \sum_i \left[\pi_{ig}\left(\tilde{p}_g\right) - \pi_{ig}\left(\tilde{p}_g\right)\right] \\ &+ \sum_i \left[S_{ig}\left(\tilde{p}_g\right) - S_{ig}\left(\tilde{p}_g\right)\right] \\ &- \sum_i b_{ig} y_{ig}\left(\tilde{p}_g\right)\left(z_{ig}^A - z_{ig}^N\right) \\ &= -\sum_i b_{ig} y_{ig}\left(\tilde{p}_g\right)\left(z_{ig}^A - z_{ig}^N\right), \end{aligned}$$

where $\tilde{p}_g$ is the unregulated world price, i.e. the solution to $\sum_i y_{ig}\left(p_g\right) = \sum_i d_{ig}\left(p_g\right)$. Hence, $\lim_{\gamma_g \to \infty}\left(W_g^A - W_g^N\right) > 0$ if $z_{ig}^A < z_{ig}^N$ for all i, which is true for sufficiently large γ_g, as long as the political parameters γ_{ig} and the supply semi-elasticities ε_{ig} are not too dissimilar across countries, as follows from the previous proposition. QED