Online Appendix

Derivation of B's incentive compatibility constraint

Proof. B's discounted stream of payoffs from cooperation with S_i must be at least as much as the one-time payoff from defection:

$$\sum_{t=0}^{\infty} \Psi(f)(f - qs)w\delta^t \geq w \tag{A1}$$

For $f < p + \tau - h$, $\Psi(f)$ will be maximized at 1 and, for $f > p + \tau + h$, $\Psi(f)$ will be minimized at 0. Thus, the relevant range for evaluating f will be $p + \tau - h \leq f \leq p + \tau + h$, for which $\Psi(f) = \frac{p + \tau + h - f}{2h}$.

Thus, Inequality A1 can be expressed as:

$$\sum_{t=0}^{\infty} \left[\frac{p + \tau + h - f}{2h} \right] (f - qs)w\delta^t \geq w \tag{A2}$$

This can be rewritten as:

$$(f - qs)(p + \tau + h - f) \geq 2h(1 - \delta) \tag{A3}$$

Solving this quadratic equation for f yields:

$$f \in \left[\frac{p + \tau + h + qs}{2} - R, \frac{p + \tau + h + qs}{2} + R \right] \tag{A4}$$

Where

$$R \equiv \frac{\sqrt{(p + \tau + h + qs)^2 - 4\left[qs(p + \tau + h) + 2h(1 - \delta)\right]}}{2} \tag{A5}$$

There is a nonempty set of values of f for which R is real. That is, it is possible for B's incentive compatibility constraint to be satisfied if:

$$(p + \tau + h + qs)^2 \geq 4\left[qs(p + \tau + h) + 2h(1 - \delta)\right] \tag{A6}$$

This can be expressed as:

$$\delta \geq \delta_{min} \tag{A7}$$

Where

$$\delta_{min} \equiv \frac{-(p + \tau + h + qs)^2 + 4qs(p + \tau + h) + 8h}{8h} \tag{A8}$$

It is also possible to express Inequality A6 in terms of B's expected penalty:

$$qs \leq EP_{max} \tag{A9}$$

Where:

$$EP_{max} \equiv p + \tau + h - \sqrt{8h(1-\delta)} \tag{A10}$$

□

Derivation of S_i's incentive compatibility constraint

S_i's incentive compatibility constraint is:

$$\Psi(f)(1-f) + (1-\Psi(f))(1-p-\tau_u) \geq 1-p-\tau \tag{A11}$$

This can be expressed as follows:

$$\Psi(f)(1-f)+(1-\Psi(f))(1-p-\tau_u) \geq \Psi(f)(1-p-\tau_o)+(1-\Psi(f))(1-p-\tau_u) \tag{A12}$$

Where the τ_o is the average transportation costs on unofficial route for smugglers who would prefer the official route and τ_u is the average transportation costs on the unofficial route for smugglers who would prefer the unofficial route. Here, $\tau_o \equiv \dfrac{f-p+\tau+h}{2}$ and $\tau_u \equiv \dfrac{f-p+\tau-h}{2}$.

In turn, this can be simplified to:

$$1-f \geq 1-p-\tau_o \tag{A13}$$

From this, we can express S_i's incentive compatibility constraint as:

$$f \leq p+\tau+h \tag{A14}$$

Proof that fixed fee is preferable to B over random fee

Proof. If $r(f)$ is the distribution function over f, S_i's expected payoff of randomized fees is:

$$Eu_R = \int_f r(f)u(w-f)\,df \tag{A15}$$

If the average fee is $\bar{f} = \int_f r(f)f\,df$, S_i's payoff for a uniform fee set at $\bar{f}$ is $u(w-\bar{f})$. If S_i is risk neutral, i.e. $u(x) = x$, then the expected utility of the randomized fee is:

$$U_R = \int_f r(f)u(w-f)\,df = \int_f r(f)(w-f)\,df = w - \bar{f} \tag{A16}$$

This is equivalent to the utility of the uniform fee set at $\bar{f}$:

$$u_U = u(w-\bar{f}) = w - \bar{f} \tag{A17}$$

Thus, in the risk neutral case, random fees and uniform fees set at the average of the random fees are equivalent. However, if S_i is risk averse, i.e. $u(\cdot)$ is concave with $u' > 0, u'' < 0$. Then by Jensen's Inequality, which states that $u(\int_x r(x)u(x)dx) \geq \int_x u(r(x))dx$ for concave $u(\cdot)$ and random variable x, S_i will strictly prefer the uniform fee to the randomized fee due to the concavity of u:

$$u(w - \bar{f}) > U_R(w - f) \tag{A18}$$

Thus, if S_i is risk averse, the expected utility that she receives from passage on the official route with random fees will be less than the utility from a uniform fee for the same average fees collected by B. That is, B can charge a higher fixed fee than the average of a randomized fee for a given smuggler S_i. Thus, if smugglers are risk averse, a uniform fee will be more profitable for B.

□

Derivation of B's optimal fee

Proof. B's optimization problem in each period is:

$$\begin{aligned} \max_f \quad & \Psi(f)(f - qs)w \\ \text{subject to:} \quad & f \in \left[\frac{p + \tau + h + qs}{2} - R, \frac{p + \tau + h + qs}{2} + R\right] \end{aligned} \tag{A19}$$

Given $\Psi(f)$ in Equation 11 and the fact that a fee set at $f = p + \tau - h$ will entail all smugglers crossing via the official route, the maximization problem can be stated as:

$$\begin{aligned} \max_f \quad & \left(\frac{p + \tau + h - f}{2h}\right)(f - qs)w \\ \text{subject to:} \quad & f \in \left[\frac{p + \tau + h + qs}{2} - R, \frac{p + \tau + h + qs}{2} + R\right] \end{aligned} \tag{A20}$$

Solving for the first order conditions yields:

$$f' = \frac{p + \tau + h + qs}{2} \tag{A21}$$

As mentioned above, if $f \leq p + \tau - h$, the total volume of smugglers who would opt for the official route would already be maximized at $\Psi(f) = 1$. That is, there is no reason for B to set the fee any lower than $p + \tau - h$. Thus, if $f' < \tau + p - h$, the optimal fee f_{opt} will be set to $p + \tau - h$. This will occur under the following condition:

$$\frac{p + \tau + h + qs}{2} < p + \tau - h \tag{A22}$$

This can be rearranged as:

$$h < \frac{p + \tau - qs}{3} \tag{A23}$$

Thus, B's optimal fee can now be expressed as:

$$f_{opt} = \begin{cases} p + \tau - h & \text{if } h < \dfrac{p + \tau - qs}{3} \\ \dfrac{p + \tau + h + qs}{2} & \text{if } h \geq \dfrac{p + \tau - qs}{3} \end{cases} \tag{A24}$$

□

Extended Model: Reward Factors

In the baseline model, we assume that if the border agent seizes the contraband, she will be able to claim the full value of the contraband. However, a border official who wishes to resell the contraband may lack the marketing networks and expertise that the smuggler has to claim the full market value of the contraband. Alternatively, a border official who dutifully does not resell the contraband, but is rewarded in career benefits such as increased salaries or promotions are likely to not be rewarded materially in the same amount as the full value of the seized contraband. Thus, to account for this scenario, we allow for the border agent to be rewarded by a proportion less than one of the arbitrage value of the contraband.

In this case, when B seizes the contraband, B's actual payoff from the seized contraband is modified by a proportion $r \in [0, 1]$, which we will call the *reward factor*, of the arbitrage value of the contraband, or rw. The magnitude of r will depend on the ability of B to extract benefits from seizing contraband, either legally or illegally. If B engages in the illicit resale of the product and has the marketing capacity to readily resell the contraband at full market value, r would equal 1. However, if B lacks the capacity to liquidate these goods, B may only be able to realize a portion of the market value of the contraband such that $r < 1$. This reward factor also applies to border agents who are not engaged in illicit reselling. The agent may be rewarded in career benefits—such as higher incomes, bonuses, or promotions—for successfully seizing contraband, particularly of higher value goods, such that $r > 0$. However, if the agent is not rewarded for seizing contraband, the reward factor will be $r = 0$.

Figure A1 presents the stage game in extensive form. For each outcome, the payoffs for S_i followed by B are presented in the parentheses.

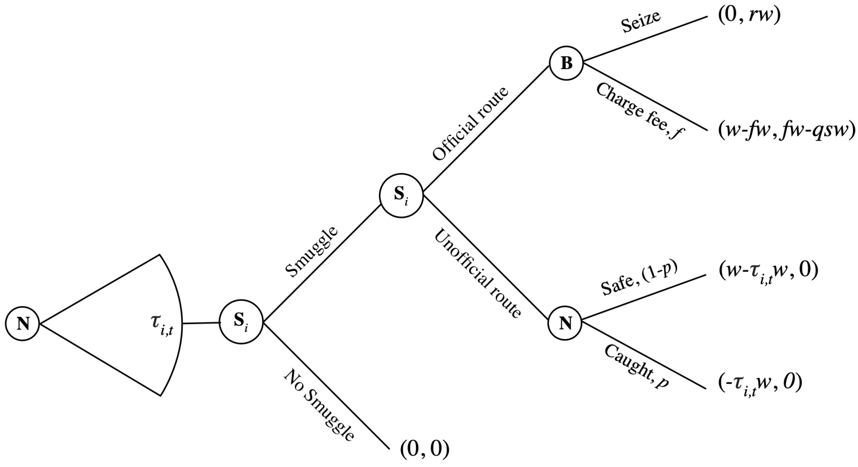

FIGURE A1. *Stage Game of Smuggling Interaction*

The structure of this game differs from the original game only in the case of B seizing the contraband. Thus, the conditions for collusive equilibria should mirror the conditions in Lemma 2, which can be derived in a similar procedure.

Lemma 5. ***Collusive Equilibria***. *In a repeated game between border agent B and smuggler S_i, a collusive strategy profile a and fee $f \in [0, 1)$ can form a subgame perfect equilibrium under the following conditions:*

$$\delta \geq 1 - \frac{\overline{V}_B(f, a, q, s)}{rw} \tag{A25}$$

$$\tau_{it} + p \geq 1 - \frac{\overline{V}_{S_i}(f, a)}{w} \tag{A26}$$

The conditions for collusive equilibria are the same as in Lemma 2, except that B condition in Equation A25 becomes less restrictive by the factor r. That is, the lower B's reward factor (B is rewarded less from confiscating the contraband), the more incentive B has to collude with S_i. Conversely, higher reward factors will provide B with greater incentives to confiscate contraband. Besides the greater attractiveness of collusion, the structure of the game is fundamentally the same. Thus, the main predictions of the baseline model will still hold.

General Maximization Problem: All Feasible Strategies and Distributions

Lemma 2 lays out the necessary conditions for both B and S_i to be able to sustain a collusive relationship.

From Equation 9, we will also define a cutpoint for the minimum transportation costs on the unofficial route, τ_{min}, above which smugglers would have an incentive to opt for the official route and enter into a collusive relationship with B, given a, p, f, and w.

$$\tau_{min}(f,a) \equiv 1 - p - \frac{\overline{V}_{S_i}(f,a)}{w} \tag{A27}$$

If $\Phi_{\tau_{it}}(x)$ is the cumulative distribution function for which S_i's transportation costs are less than some threshold x following Equation 9, then $\Phi_{\tau_{it}}(\tau_{min})$ is the total proportion of S_i who would prefer the unofficial route. Thus, the proportion of S_i who prefer the official route is:

$$1 - \Phi_{\tau_{it}}\left(\tau_{min}(f,a)\right) \tag{A28}$$

For simplicity, we assume that smuggler-agent pairs who meet the conditions in Lemma 2 will be able to establish collusive relationships. B's payoff $\pi(f,a)$ can therefore be expressed as:

$$\pi(f,a) = \left[1 - \Phi_{\tau_{it}}(\tau_{min}(f,a))\right](f - qs)w \tag{A29}$$

We can express B's optimization problem as:

$$\begin{aligned} \max_{f,a} \quad & \left[1 - \Phi_{\tau_{it}}\left(\tau_{min}(f,a)\right)\right](f - qs)w \\ \text{subject to} \quad & \delta \geq 1 - \frac{\overline{V}_B(f,a,q,s)}{w} \end{aligned} \tag{A30}$$

Notice that B faces a tradeoff between the fee and the number of smugglers who pay it, *ceteris paribus*. That is, a higher fee will decrease the number of smugglers who choose the official route, since $\partial\overline{V}_B(f,a,q,s)/\partial f < 0$. Thus, the agent's optimization problem is to set the fee that maximizes her payoffs, while balancing the fee and the volume of smugglers on the official route. The fee f_{opt}, which optimizes B's payoffs, is given by solving for the first-order conditions $\partial\pi/\partial f = 0$ for a given strategy profile a, which yields:

$$1 - \Phi_{\tau_{it}}\left(1 - p - \frac{\overline{V}_{S_i}(f_{opt},a)}{w}\right) - \frac{(f_{opt} - qs)\phi_{\tau_{it}}\left(1 - p - \overline{V}_{S_i}(f_{opt},a)\right)}{w}\frac{\partial\overline{V}_{S_i}(f_{opt},a)}{\partial f} = 0 \tag{A31}$$

Here, $\phi_{\tau_{it}}(\cdot)$ is the corresponding probability distribution function for $\Phi_{\tau_{it}}(\cdot)$.

Raised Cosine Distribution

In this section, we examine the model using the raised cosine distribution instead of the uniform distribution. The cumulative distribution function of the raised cosine distribution for some threshold x is given as:[83]

$$\Phi_{\tau_{it}}(x) = \begin{cases} 0, & \text{for } x \leq \mu - s \\ \frac{1}{2}\left[1 + \frac{x-\mu}{s} + \frac{1}{\pi} sin\left(\frac{\pi}{s}(x-\mu)\right)\right], & \text{for } \mu - s \leq x \leq \mu + s \\ 1, & \text{for } x \geq \mu + s \end{cases} \quad \text{(A32)}$$

Where μ is the mean and s is the phase length of the cosine curve.

The raised cosine distribution has the advantage of having a single peaked shape, similar to the normal distribution, while also meeting the requirements that the distribution has support over finite bounds and the mean is orthogonal to the variance and other shape parameters.

Because Equation A31 lacks an analytical solution for $\Phi_{\tau_{it}}(f - p)$ in Equation A32, we illustrate this relationship numerically with a contour graph of f_{opt} as a function of various values of $p \in [0, 1]$ and $\tau \in [0, 1]$ for a given standard deviation.[84]

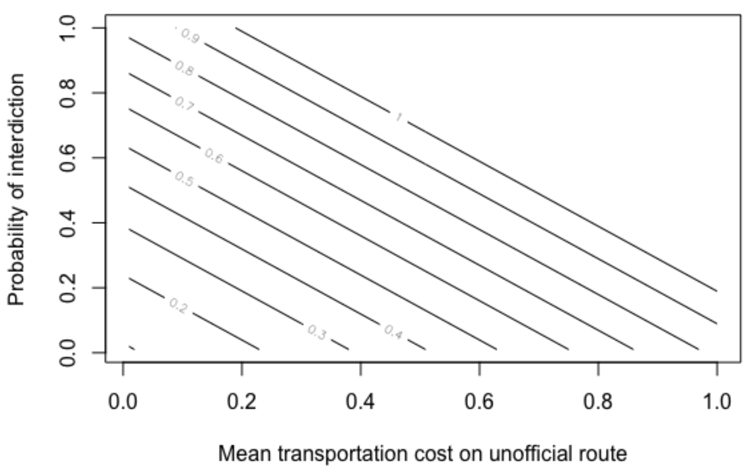

FIGURE A2. *Fee f_{opt} that maximizes B's payoffs, where constraint does not bind*

The proportion of smugglers who opt for the official route collusion is incentive compatible, $1-\Phi_{c_i}(f_{opt})$, can be seen in the contour plot in Figure A3. The plot shows

83. Rinne 2010, 116.

84. We can obtain the standard deviation of the τ_{it} from the phase length l as follows: $\sigma = l\sqrt{1/3 - 6/\pi^2}$ Rinne 2010, 118.

that at a given σ an increase in transportation costs τ or probability of interdiction p will result in an increase in smugglers on the official route.

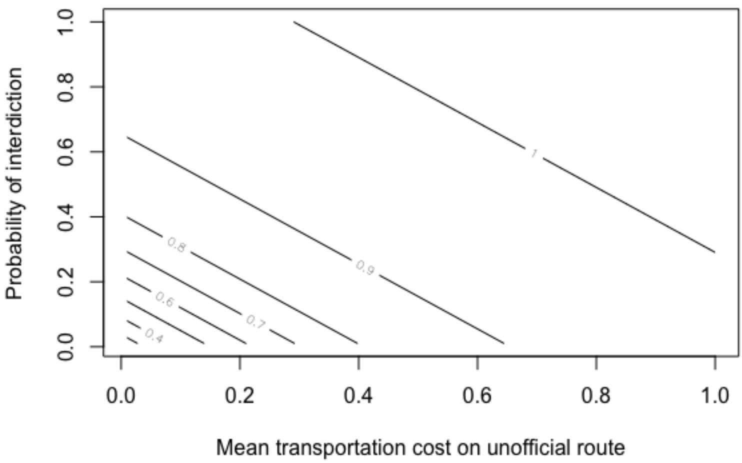

FIGURE A3. *Proportion of smugglers opting for official route*

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