



# Validating Deterrence Models for Scanning Technologies

By George Thompson

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## Abstract

The use of scanning systems (e.g., radiation portal monitors and X-ray imagers) at border checkpoints is said to act as a deterrent to the smuggling of radiological/nuclear materials, drugs, and other illicit items. Can such deterrent effects be measured? The author examines “extended” screening models that incorporate the motivations, perceptions, and decision-making behaviors of different smuggling populations. Model predictions are compared to individual cases of radiological/nuclear smuggling and aggregated data on drug smuggling. These comparisons point to tentative conclusions regarding conditions under which scanning systems might act as a deterrent. Such conclusions are limited by a reliance on open-source information, the small number of cross-border radiological/nuclear smuggling cases on record, the high level of aggregation in the drug smuggling data used, the need to make very rough estimates of some intermediate variables, and the fact that cognitive and behavioral models have not been validated for the specific populations being studied here.

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## Introduction

Large-scale scanning systems,<sup>1</sup> such as X-ray imagers and radiation portal monitors, are important tools in combating the smuggling of dangerous materials. Although their principal contribution has been to *detect* such materials, they are also said to help *deter* smuggling activity.<sup>2</sup> Can this effect be measured?

This article holds that it is possible to measure the deterrent effect of scanning systems using an indirect approach based on face validation of extended screening models, defined as models that reflect the motivations, perceptions, and behaviors of different smuggling populations. It follows from this definition that the deterrent effect of scanning systems may depend on exactly who is being deterred and what type of smuggling they are contemplating. Accordingly, two very different types of activity are considered: the worldwide smuggling of radiological/nuclear materials<sup>3</sup> and the smuggling of illegal drugs across land ports of entry (LPOEs) at the southwest border (SWB) of the United States.<sup>4</sup> The analysis focuses on large-scale systems, while recognizing the contribution of other types of equipment (such as small handheld detectors) and protocols.

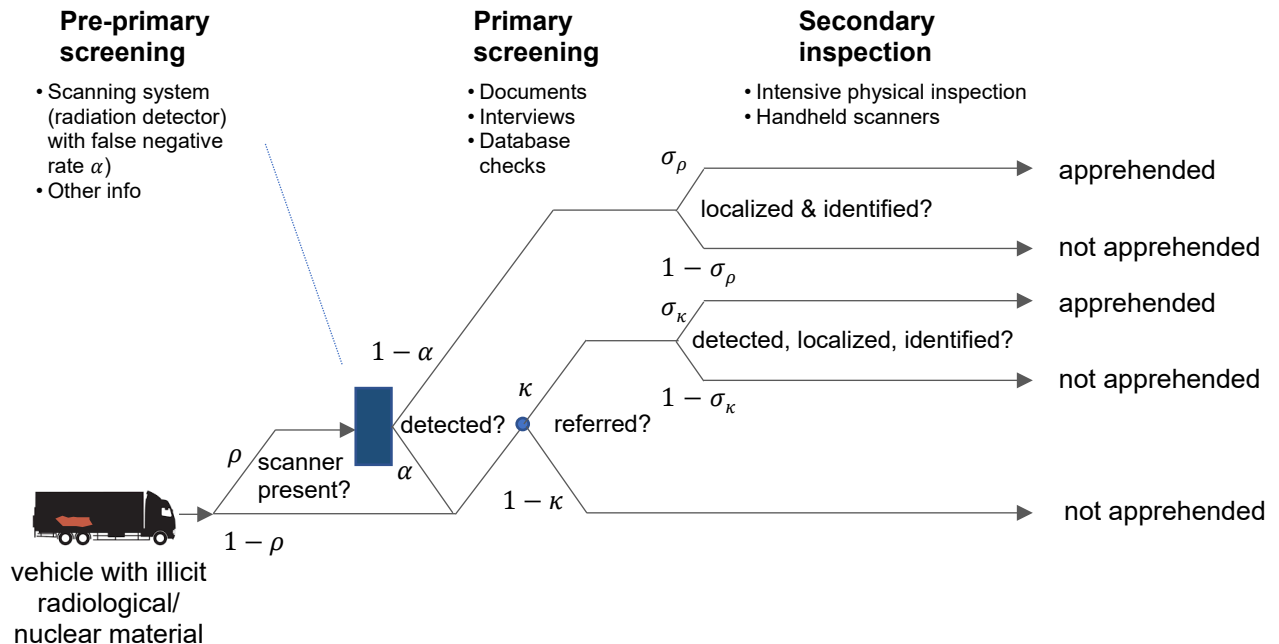
This research used only publicly available, open-source information—a significant limitation. However, the framework developed here could be also applied with a more robust data set.

## Elements of the Extended Model

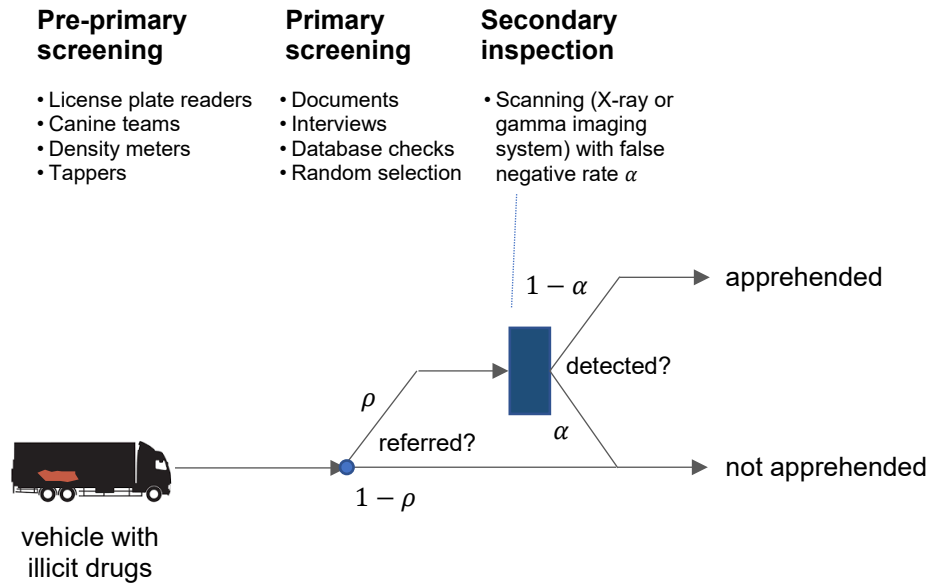
The deterrent effect of scanning systems depends on the complex interrelationship of technical factors (such as the systems' ability to identify specific materials of interest) and human factors (such as the willingness of smugglers to risk detection). The so-called extended model provides a framework that includes both types of factors. The following sections introduce the basic elements. For a mathematical treatment, see Appendices A through C.

## Screening and Scanning

Scanning systems operate within a larger screening architecture.<sup>5</sup> Figures 1 and 2 depict typical checkpoint screening processes for radiological/nuclear and drug smuggling, respectively.<sup>6</sup>



**Figure 1:** Checkpoint Screening; Radiological/Nuclear Smuggling



**Figure 2:** Checkpoint Screening; Drug Smuggling

Figure 1 indicates that for radiological/nuclear smuggling, scanning systems (typically, radiation portal monitors) are used in primary screening. The probability of apprehension is driven by the likelihood that a scanner will be present ( $\rho$ ), that it will detect the radiation source ( $1 - \alpha$ ), and that the resulting secondary inspection will localize and identify the source ( $\sigma_p$ ). As Figure 2 indicates, the screening architecture for drug smuggling is different. Here, a variety of factors (including the subjective judgement of customs officials) impact the probability that the incoming vehicle will be referred to secondary inspection ( $\rho$ ) and scanned. Scanning (typically, by X-ray or gamma imaging systems) will determine the probability that the contraband is detected ( $1 - \alpha$ ).

## Deterrence Thresholds

Given scanning systems with parameters  $\rho$  and  $\alpha$ , deterrence—defined here as the decision not to carry out a contemplated smuggling attempt because of the presence of those systems—occurs if the probability of “failure” (from the smuggler’s point of view) exceeds some threshold  $\tau$ . Thus, the extended model must link the parameters  $\rho$  and  $\alpha$  (along with other parameters) to smugglers’ estimates of  $\tau$ .

Because radiological/nuclear smuggling comprises a small number of discrete incidents, thresholds can be estimated for each documented case. In analyzing a set of cases, or an activity such as drug smuggling that occurs at a very high volume, thresholds are distributed over an interval  $[\tau_1, \tau_2]$ . When the perceived probability of failure is less than  $\tau_1$ , no deterrence occurs; as it increases from  $\tau_1$  to  $\tau_2$ , smuggling attempts decrease to zero; beyond  $\tau_2$ , deterrence is absolute.

If smuggling occurs and smugglers' a-priori estimates of failure are known, those estimates provide a lower bound for  $\tau_2$ . It is more difficult to estimate  $\tau_1$ : one would need to know that a planned smuggling attempt did *not* occur specifically because of the presence of scanning systems.

## **Definitions of “Success” and “Failure”**

If each attempt is an isolated event, the detection of that attempt constitutes failure. This perspective is applicable to radiological/nuclear smuggling, which is largely the province of individual opportunists and small groups of criminals.<sup>7</sup> By contrast, drug smuggling is a large, ongoing enterprise: for a drug trafficking organization (DTO), failure occurs when the number or proportion of smuggling attempts that are detected results in unacceptably low profits.<sup>8</sup>

## **Perceptions**

An amateur radiological/nuclear smuggler may have no better knowledge regarding the prevalence and effectiveness of portal monitors (i.e., the values of  $\rho$  and  $\alpha$ ) than what an interested member of the public could discover from news releases and other such information. Criminal groups, however, may have knowledge of operations at specific border crossings, the flexibility needed to exploit coverage gaps, and/or the ability to evade scanning altogether (e.g., through bribery).<sup>9</sup> In such cases, the perceived probability of detection may be near zero despite the general prevalence of scanners along a given border.

DTOs can estimate the chances of referral and detection fairly accurately, based on repeated observations (see Appendix B). A single major DTO may be able to make tens of thousands of such observations per year.<sup>10</sup>

## **Risk Tolerance**

The decision to smuggle is essentially a risk proposition involving potential gains and losses under conditions of uncertainty. Two key questions are: 1) what are the potential gains and losses for a given smuggling type and population; and 2) how do smugglers weigh uncertain gains and losses?

## **Potential Gains and Losses**

Radiological/nuclear smugglers are primarily motivated by profit.<sup>11</sup> The amounts they expect to receive from a single successful smuggling attempt range from tens to hundreds of thousands of dollars.<sup>12</sup> These amounts loom large in the Transcaucasus and the Black Sea regions, where most recent smuggling incidents have occurred.<sup>13</sup> Annual incomes there are typically under \$5,000—closer to \$1,000 in poorer areas.<sup>14</sup> Typical sentences for convicted smugglers may be on the order of two to four years' imprisonment for a “mule” and perhaps seven to ten years for a planner or organizer.<sup>15</sup> We do not know how smugglers weigh such punishments against prospective gains from smuggling; however, under the simplest assumption—i.e., imprisonment equals lost income—gains appear to outweigh losses by severalfold, suggesting that deterrence is difficult and thresholds may be high.

Drug mules are also financially motivated. Mean payments are approximately \$1,600 per load, with 10th and 90th percentiles at \$500 and \$3,000, respectively.<sup>16</sup> Average per-capita wages are approximately \$30,000 in U.S. and \$13,500 in Mexican border counties; however, many mules are teens, homeless individuals, or convicts, with lower- than -average incomes. Punishments are relatively light: even a large load of cocaine can draw a sentence of just three years for a first-time offender, and sentences average less

than two years for marijuana loads as large as 200 pounds. Smugglers under 18 years of age may face only a fine—perhaps paid by their parents—and a few weeks in a juvenile detention center.<sup>17</sup>

For DTOs (as opposed to individual mules), the only loss that occurs when a load is detected is the lost income from the sale of the drugs; in other words, seizures impact the profit margin by raising the “cost of doing business” (see Appendix D).

## **Decision-making Models**

Two prominent theories purport to explain how decision makers—including criminals—weigh uncertain gains and losses: Expected Value Theory (EVT) and Cumulative Prospect Theory (CPT).

EVT is based on the concept of “rational choice”—the notion that an individual will commit a crime if the expected gain (i.e., probability times magnitude) exceeds the expected loss. If it does not, he or she will be deterred. The probability of detection for which expected gains and losses are equal is the deterrence threshold  $\tau$ . Many researchers over the past several decades have attempted to validate this theory with respect to criminal behavior and deterrence. The record is rather mixed: a recent survey finds that “the state of deterrence theory [based on rational choice models] is still confusing. ... It seems as though deterrence works for some people, but not for others. Some individuals are ‘detrable,’ while others are not...”<sup>18</sup>

CPT is based on the observation that human decision makers do not always make optimal decisions; rather, they use heuristics and other cognitive shortcuts that can be modeled. CPT models, like EVT models, can be used to generate quantitative predictions for deterrence thresholds. One prediction of the standard CPT model is that individuals treat gains and losses asymmetrically: that is, gaining a benefit of a certain magnitude is less important than avoiding a loss of the same magnitude. A corollary is that the deterrence threshold for a decision to continue smuggling is much higher than the threshold for a decision to begin.

Although both EVT and CPT models can incorporate a wide range of factors and appear to account for much observed behavior, it is worth pointing out that many factors cannot be easily translated into gains and losses. Examples include the effects of ideological commitments, ethnic identity, gang affiliation, or

intangibles such as the value of freedom from incarceration. For additional details regarding EVT and CPT models, including a quantitative treatment, see Appendix C.

## **Analysis of Radiological/Nuclear Smuggling**

### **Incidents of Interest**

The author reviewed and characterized relevant radiological/nuclear smuggling incidents in terms of date and location, type of radionuclide involved, mass and/or activity of the source, presence or absence of shielding, and presence or absence of a large-scale scanning system. Other details, if available, were also noted: for instance, number of individuals involved, financial compensation sought, and whether and how the material was detected (e.g., as the result of a “sting” operation, border official’s hunch, or portal monitor alarm).

One key source was the CNS Global Incidents and Tracking Database, maintained by the James G. Martin Center for Nonproliferation Studies (CNS) on behalf of the Nuclear Threat Initiative (NTI).<sup>19</sup> As of October 2019, it described over 1,150 incidents that have occurred since 2013. NTI’s “NIS Nuclear Trafficking Collection” contains open-source abstracts of earlier incidents.<sup>20</sup> Other compendia, news reports and case studies were also consulted.<sup>21</sup>

Although these sources list many incidents, most are not relevant to this analysis (for example, incidents involving failure to secure materials, or seizure of stolen materials outside the context of smuggling). Sixty-four cross-border smuggling incidents were selected; the author was able to characterize 56 of them sufficiently for analysis purposes.

## Prevalence of Detection Systems

Some radiation detection systems were deployed within the former Soviet Union (FSU) during the 1990s. Most, however, lacked reliable neutron-detection capability.<sup>22</sup> More capable, large-scale systems were introduced under the Department of Energy's Second Line of Defense (SLD) program, which began deploying them to Russian road and rail crossings, airports and seaports in 1998. The program's scope expanded in 2001 to include other FSU states and eastern European countries; it has since widened even further. Under its current designation (the Nuclear Smuggling Detection and Deterrence (NSDD) program), it includes over 60 partner countries, with approximately 4,000 radiation portal monitors (including over 100 large-scale mobile systems) collectively covering over 500 international border crossings, including approximately 100 airports and 300 land border crossings.<sup>23</sup>

The author used open-source data to develop rough quantitative estimates of detector prevalence at various national borders over time, from 1993 through 2018. These estimates are surrogates for an unsophisticated smuggler's perception of the odds of encountering such a detector ( $\rho$ ).

## Effectiveness of Detection Systems

For a given radionuclide, the operational false negative rate of the scanner ( $\alpha$ ) can, in theory, be modeled as a function of the mass and/or activity of the source; its physical configuration; the source-detector geometry; the nature and thickness of attenuating materials (e.g., truck or container walls, other cargo); the speed at which the vehicle passes through the portal; and so on. In practice, this type of information is not usually available. Instead, detection effectiveness ( $1 - \alpha$ ) is estimated per Figure 3.

Source	Packaging	Detector Effectiveness		
		Shielded	Unshielded	Unspecified
Nuclear (Pu)		0.95	0.95	0.95
Nuclear (U)		0.20	0.90	0.90
Large radiological		0.50	1.00	1.00
Small radiological		0.20	0.95	0.95

“U” includes: Highly Enriched Uranium (HEU) (typically ~1g to 1kg); Low Enriched Uranium (LEU) (typically ~1 to 10 kg), and U238, Depleted Uranium (DU) or Uranium Oxide (typically, ~10kg or more)  
“Large radiological” designates a source with activity measured in the *kCi* to *MCi* range  
“Small radiological” designates a source with activity measured in the *μCi* to *mCi* range

**Figure 3:** Estimated Radiological/Nuclear Detector Effectiveness

These estimates are broadly consistent with summary statements in the open literature.<sup>24</sup>

It is much more difficult to estimate the effectiveness of the secondary inspection process (denoted as  $\sigma_p$  in Figure 1), which depends on such factors as the exact placement of handheld detectors, the thoroughness of the search, the presence of benign emitters that may mask the source, and the alertness of the inspector. Covert field tests are designed to provide insight into this value; however, results of such tests are not publicly available.<sup>25</sup>

### Case-By-Case Analysis

Of the 56 incidents considered, some 25 occurred prior to 2004, while detectors were not widespread and smugglers likely believed—correctly—that their chances of being detected at a border checkpoint were low. A 2002 Government Accountability Office (GAO) report paraphrased one official to the effect that “a dedicated nuclear smuggler has a 90 percent chance of successfully defeating his country’s border controls.”<sup>26</sup> A “failure” rate of 0.10 or less is consistent with the author’s rough estimates of detector prevalence over the period 1993-2004.

In approximately 20 of the post-2004 incidents, it appeared that smugglers’ a-priori estimates of the probability of failure might be much higher: 25, 30, 40 percent or more. These cases were reviewed carefully to determine which, if any, might represent deliberate challenges at such odds. Eleven incidents

had alternative explanations: in one case, for example, border officials had clearly been bribed; in two cases, routine checks had been discontinued at the specific crossings where the incidents occurred; other cases involved disputed alarms, or incidents that may have been unwitting.<sup>27</sup>

In the remaining nine cases (shown in Figure 4) it is possible that smugglers made the attempt despite a relatively high detection probability. However, available information is not conclusive and other explanations are possible. For example, cases 44 through 47 coincided with increased portal monitor deployments in Kazakhstan.<sup>28</sup> Unsophisticated smugglers may have been unaware of this development; conversely, criminals may have counted on evading these detectors. The remaining five cases coincided with periods of higher- than- normal corruption among local officials:<sup>29</sup> again, smugglers may have counted on eliminating the chance of detection through bribery.

#	Date	From	To	Material Type	Shielded?	Detector Present?	A priori Prob Failure Prior Knowledge of Detector?	
							No	Yes
44	11-Sep-08	Kazakhstan	Russia	Rsm		Y	0.20	0.50
45	13-Apr-09	Czech	Russia	Rlg		Y	0.25	0.50
46	20-Jul-09	Kazakhstan	Russia	Rsm			0.25	
47	30-Jul-09	Kazakhstan	Russia	Rlg	N	Y	0.25	0.50
54	30-Apr-14	Moldova	Ukraine	U			0.25	
55	4-Aug-14	Armenia	Georgia	Rsm			0.25	
56	25-Aug-14	Kazakhstan	Uzbekistan	Rsm		Y	0.30	0.50
62	5-Aug-15	Ukraine	Romania	U			0.20	
63	11-Jan-16	Armenia	Georgia	Rsm			0.30	

**Figure 4:** Radiological/Nuclear Smuggling Cases Possibly Relevant to Deterrence

If it were known that Figure 4 accurately reflected smugglers' a-priori estimates of detection in at least one case, it would be tempting to conclude that the threshold for absolute deterrence ( $\tau_2$ ) was 0.20 to 0.50 or higher. Actually, these numeric values are largely driven by the use of a "placeholder" value (0.50) for the unknown effectiveness of secondary inspection ( $\sigma_p$ ). Thus, it would be more accurate to estimate the lower limit for  $\tau_2$  as  $0.40\sigma_p$  to  $1.00\sigma_p$ .

Interestingly, there is some information that bears directly on the threshold at which deterrent effects begin ( $\tau_1$ ). A 2016 GAO report alludes to one or more incidents in which it was subsequently learned that scanning systems *did* deter a crossing.<sup>30</sup> If the associated a-priori detection probabilities were known, they would establish an upper bound for  $\tau_1$ . Even without knowledge of those values, one can safely say that they do not exceed  $\sigma_\rho$  (in other words, even if a scanning system is present and works perfectly, the probability of detection and apprehension is limited by the effectiveness of the secondary inspection).

## **Implications of Decision-making Models**

Given that the prospective gains from radiological/nuclear smuggling may be roughly two to five times the magnitude of the losses, the “standard” CPT model predicts that deterrence would require a-priori estimates of detection and apprehension to lie in the range 0.40 to 0.70.<sup>31</sup>

(Under the EVT model, thresholds would be even higher. See Appendix C.)

## **Conclusions (Radiological/Nuclear Smuggling)**

Taken together, the above findings suggest that<sup>32</sup> for radiological/nuclear smuggling,

$$\tau_1 \cong \min(0.40, \sigma_\rho)$$

$$\tau_2 \cong \max(0.70, \sigma_\rho)$$

where  $\sigma_\rho$  is the perceived effectiveness of the secondary inspection. The strength of this conclusion is limited by the small number of cases and the incomplete nature of the available information. In addition, this conclusion rests on several assumptions that can be questioned:

- Smugglers monetize the consequences of imprisonment based on lost income.
- Smugglers believe that if detected they will be convicted and imprisoned for a full term.

- Smugglers believe that a successful (i.e., undetected) border crossing will allow them to realize the potential gains from the sale of the material (in other words, post-crossing risks or uncertainties are considered minimal).
- Results of prior researchers' controlled experiments on decision making under conditions of uncertainty can be extrapolated and applied to other populations—specifically, to would-be radiological/nuclear smugglers.
- At least one of the incidents analyzed in this study represents a deliberate challenge to the detection architecture under prior knowledge that radiation portal monitors were probably or certainly present.

Available information does not allow us to draw any conclusions about deterrence for detection probabilities that lie between  $\tau_1$  and  $\tau_2$  (for example, whether the probability of making an attempt decreases linearly or in some other fashion).

## **Analysis of Drug Smuggling at Southwest Border Land Points of Entry**

### **Drug Smugglers and Drug Smuggling**

The volume of drug smuggling observed at Southwest Border Land Points of Entry (SWB LPOEs) is considerable: per Figure 5, some 15,000 loads per year are seized there.<sup>33</sup> Seizures are variously estimated at 10 to 20 percent of total traffic;<sup>34</sup> thus, there may be as many as 150,000 attempts per year.

Estimated Number of Seizures at SWB LPOEs (#)						
FY	Cocaine	Heroin	Marijuana	Metham-phetamines	Fentanyl	Total (# in thousands)
<b>2014</b>	1,200	1,100 – 1,140	2,900 – 3,400	2,400	N/A	<b>7.6 – 8.1</b>
<b>2015</b>	1,400	1,300 – 1,580	2,800 – 4,700	3,100	2	<b>8.6 – 10.8</b>
<b>2016</b>	1,600	1,000 – 1,110	2,500 – 4,000	4,100	20	<b>9.2 – 10.8</b>
<b>2017</b>	2,000	890	1,600 – 2,900	5,700	87	<b>10.3 – 11.6</b>
<b>2018</b>	1,700	1,370	1,300 – 2,300	7,000	182	<b>11.6 – 12.6</b>
<b>2019</b>	2,900	1,420	1,300 – 2,300	8,400	244	<b>14.3 – 15.3</b>

**Figure 5:** Estimated Number of Drug Seizures at SWB LPOEs

Most attempts involve passenger vehicles and tractor trailers. Drugs are typically carried in hidden locations: inside doors; behind vehicle panels; within truck walls or underneath floors; in false compartments; within spare tires and wheel rims; or inside vehicle batteries, axles, and drive shafts. They may be concealed within shipments of legitimate goods—alongside or mixed with the contents of containers of legitimate goods.<sup>35</sup> Drug-laden vehicles are not always driven by smugglers: powerful magnets, surreptitiously attached to vehicle undercarriages, have been used to turn trusted travelers into unwitting drug mules.<sup>36</sup>

## Screening and Scanning Effectiveness

### Pre-Primary and Primary Screening

The effectiveness of the primary screen,  $\rho$ , is difficult to measure, since “ground truth” (i.e., which vehicles really are carrying drugs) is unknown.<sup>37</sup> However, it would appear that the primary screen is at least somewhat more effective than a purely random selection strategy. In other words, the true value of  $\rho$  is most likely higher than the current referral rate (0.02 for privately owned vehicles (POVs) and 0.16 for tractor-trailers).<sup>38</sup>

Drug smugglers are notorious for underestimating detection probabilities.<sup>39</sup> They may well believe that their odds of facing secondary inspection are no worse than any other crosser's, particularly at low referral rates. However, given that smuggling organizations make thousands of attempts per year, it is unlikely they would underestimate true screening effectiveness by more than 15 percent (see Appendix B). Therefore, the perceived value of  $\rho$  is assumed equal to the current referral rate, with the true value up to 15 percent higher.

## **Secondary Inspection and Scanning**

Scanning effectiveness increased significantly with the introduction of so-called backscatter systems in 2008. By capturing information from radiation that is scattered away from an object, these systems can detect the presence of lower-density organic matter, such as hidden drugs.

Receiver operating curves, operational test results, and other such data are not available in the open literature,<sup>40</sup> nor are the results of CBP's covert tests of these systems.<sup>41</sup> SAIC's Vehicle and Cargo Inspection System (VACIS®), a gamma imaging system, has demonstrated 97 percent effectiveness in determining whether a truck is empty.<sup>42</sup> Lower-contrast scenarios are undoubtedly more challenging; still, a large load of drugs might be difficult to conceal from current systems. Accordingly, this analysis took  $(1 - \alpha) = 0.95$ .

Scanning systems' employment is constrained by their size, cost, and throughput. Given the volume of traffic entering the United States from Mexico (70 to 90 million POVs and 5 to 10 million trucks per year<sup>43</sup>) and the fact that a single scan can take eight minutes,<sup>44</sup> these systems are normally used in secondary inspection only.

## **Organizational Model**

The number of major Mexican DTOs is currently estimated at six to nine, although some observers have noted increasing fragmentation.<sup>45</sup> Major DTOs employ a “multi-nodal” model, contracting specialized services (growing, processing, cross-border smuggling, money laundering, etc.) to peripheral cells that are mutually independent.<sup>46</sup> This arrangement minimizes risk (since each cell possesses limited information and is unlikely to compromise others), provides resilience (since a single cell can be replaced rapidly if disrupted), and promotes agility (since it is easy to expand or contract as market conditions warrant, or to move into new criminal markets).

Accordingly, deterrence is considered at three levels: the major DTO, the local or regional smuggling cell, and the individual drug mule.

## **Deterrence--Major DTOs**

At first blush, it seems the most one can say is that the deterrent effect of current scanning systems is far from absolute. Can one predict what would happen if detection probabilities were to increase?

Unfortunately, deterrence is unlikely to be the first reaction. Instead, DTOs can redefine “success,” without incurring additional risk, by modifying their business model: increasing shipments / attempts and, if necessary, production; accepting a larger proportion of lost shipments; raising prices; or accepting a slightly lower profit margin. Unless the increase in detection probability is extreme, some combination of these measures is likely viable: the price elasticity of demand for illegal drugs is believed to be modest and the markup for crossing the border can double or triple the sales price,<sup>47</sup> suggesting ample room for adjustment. Appendix D uses elements of the extended model to show how detection probabilities as great as 0.50 might be accommodated with little or no increased risk.

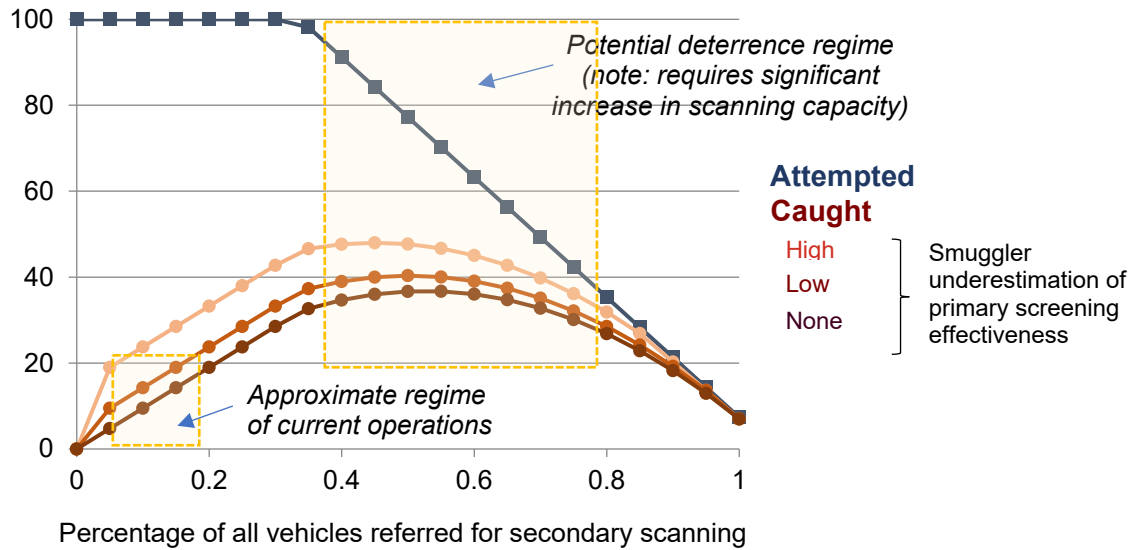
Even if a DTO faces increased risk, deterrence may not be the result. First, the organization can change smuggling pathways to maintain the most favorable results.<sup>48</sup> Second, it can interpret enhanced enforcement

as a signal to improve its operations by investing in innovation to maintain competitive advantage, for example, by financing the development of new smuggling methods and technologies.<sup>49</sup> Third, it can simply accept the added risk, consistent with both the organizational model and the tenets of CPT.<sup>50</sup>

In short, it is difficult to say quantitatively how major DTOs might be deterred by scanning technologies, because not enough is known about their business models.<sup>51</sup>

## **Deterrence –Smuggling Cells**

Mexican smuggling cells tolerate the loss of as many as 3 of every 10 shipments.<sup>52</sup> This figure is consistent with prior studies of limited-scale enforcement operations and interviews with smugglers.<sup>53</sup> Those studies concluded that deterrent effects begin when detection probabilities exceed 0.30 and increase linearly thereafter, with absolute deterrence requiring a detection probability of 1.00.<sup>54</sup> If these results are generalizable—a major assumption—they can be used, in conjunction with the other elements of the extended model (Appendix A) to predict the observable effects of increased scanning, as shown in Figure 6.



**Figure 6:** Predicted Deterrence; Drug Smuggling Cells

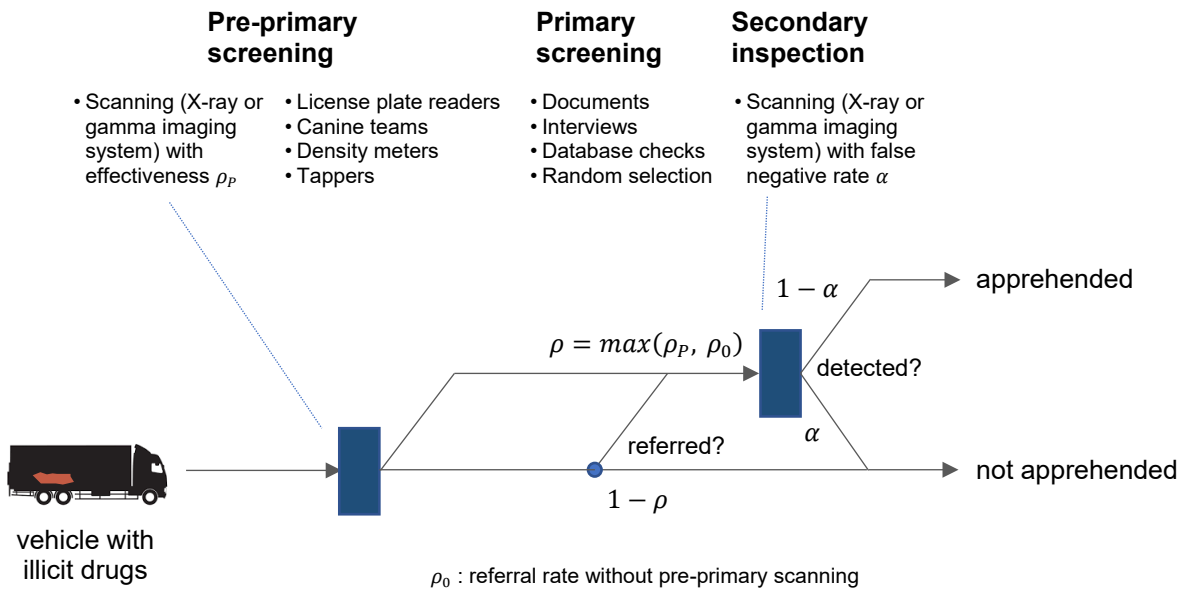
The number of smugglers caught should increase with increased referral and scanning, but only up to a point. Further increases in scanning rate will begin to deter some attempts; hence, the observed number of seizures will decline despite the increased detection probability.

Unfortunately, this approach to deterrence is not feasible, because it relies on increasing the referral rate for all vehicles, including innocent ones. If the increase is temporary (an enforcement “surge”), smugglers can wait it out. If it occurs only at selected LPOEs, smuggling cells can choose alternate paths (a phenomenon known as “displacement”). And a permanent increase in the general referral rate at all LPOEs to 0.30 or more would bring legitimate commerce to a standstill and/or require an enormous increase in CBP resources.

As it happens, a new generation of scanning systems might literally change this picture. In a 2019 pilot program, CBP acquired four in-ground X-ray systems designed to scan the undercarriage of every vehicle during the pre-primary screen. The scan takes less than one minute and would have little or no impact on vehicle wait times. Other drive-through, pre-primary scanners are also under development.<sup>55</sup> (At the time this research was conducted, these systems had not been fully tested.) If all vehicles were scanned in this

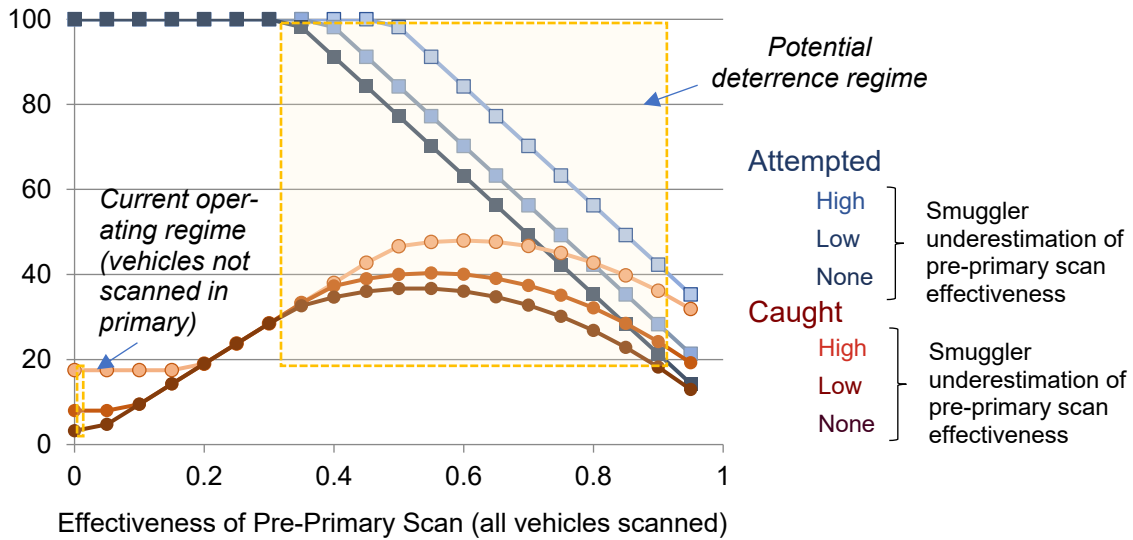
way, the increase in  $\rho$  would depend only on the effectiveness of the new system—assuming that its false positive rate ensured a negligible impact on the number of innocent referrals.

Figure 7 shows the screening architecture, modified to include pre-primary scanning. If the scan does not yield a detection, the vehicle is checked with canines, density meters, and/or tappers as before. Primary screening effectiveness is therefore  $\rho = \max(\rho_P, \rho_0)$ , where  $\rho_P$  is the effectiveness of the new scanner and  $\rho_0$  is the effectiveness without the scanner. (At worst, the new system will yield no improvement over current methods.)



**Figure 7:** Checkpoint Screening; Drug Smuggling (With Pre-Primary Scanning)

Figure 8 shows the corresponding predictions for attempts and seizures, as a function of  $\rho_P$ .<sup>56</sup>



**Figure 8:** Predicted Deterrence; Drug Smuggling Cells (With Pre-Primary Screening)

Figure 8 represents a testable prediction of the potential deterrent effects of this new generation of scanners. The underlying assumptions are a) the new systems are deployed to all SWB LPOEs; b) they are not susceptible to countermeasures; and c) the reaction of Mexican smuggling cells will be similar to that of Colombian cocaine smugglers in prior studies.

## Deterrence –Drug Mules

Current detection rates do not deter large numbers of drug mules. For an individual at the Federal poverty level,<sup>57</sup> the CPT model (Appendix C) predicts that an offer of \$500, weighed against a possible 3 years' imprisonment, would be sufficient inducement to smuggle, provided that POV referral rates stay at their current level of 0.02. A 50 percent increase in referrals (to 0.03) could be overcome, in terms of deterrent effect, by raising the payment just 38 percent (to slightly less than \$700). Under these circumstances, it is no surprise that recruiting drug mules is literally as simple as posting a job ad on Facebook.<sup>58</sup>

Statistical analysis shows that payments to mules are strongly correlated with risk factors such as the size of the load, the likelihood of detection, and the severity of possible sentences.<sup>59</sup> Moreover, first-time smugglers are offered incentive payments,<sup>60</sup> consistent with the CPT prediction that a decision to begin

smuggling carries a lower deterrence threshold (and therefore requires a greater inducement) than the decision to continue.

Smuggling cells target risk-seeking individuals, for whom the deterrent effects of increased enforcement are even less than average. Increased recruitment of teenagers, including those who are impoverished, involved in gang-related activity, or otherwise susceptible, reflects this approach.<sup>61</sup>

Extremely large increases in scanning rates could, in theory, have a more dramatic impact. For example, if detection probabilities were increased not from 0.02 to 0.03, but rather from 0.02 to 0.50, the CPT model predicts that a \$500 inducement would need to grow to \$25,000. It is hard to imagine smuggling cells sustaining an increase of this magnitude. These considerations may be reflected in the deterrence predictions for smuggling cells (previous subsection).

## Summary and Conclusions

The deterrent effect of scanning systems depends on the smuggler and the nature of the contemplated activity. Radiological/nuclear smuggling and drug smuggling are fundamentally different in ways that impact deterrence; some of these are listed in Figure 9.

	Radiological/Nuclear Smuggling	Drug Smuggling at SWB LPOEs
Level of activity (incidents per year)	<ul style="list-style-type: none"> <li>• ~2</li> </ul>	<ul style="list-style-type: none"> <li>• ~150,000</li> </ul>
Nature of activity	<ul style="list-style-type: none"> <li>• Isolated incidents</li> </ul>	<ul style="list-style-type: none"> <li>• Ongoing enterprise; established supply chain</li> </ul>
Smuggling populations	<ul style="list-style-type: none"> <li>• Individuals/opportunists and small groups of criminals</li> </ul>	<ul style="list-style-type: none"> <li>• Large DTOs</li> <li>• Smuggling cells</li> <li>• Individual mules</li> </ul>
End users/demand	<ul style="list-style-type: none"> <li>• Unknown</li> </ul>	<ul style="list-style-type: none"> <li>• Distributors, dealers, drug users</li> </ul>
Scanning systems	<ul style="list-style-type: none"> <li>• Passive radiation detection (portal monitors, mobile vans)</li> </ul>	<ul style="list-style-type: none"> <li>• Active imaging (X-ray and gamma imagers)</li> </ul>
Scanning role within checkpoint screening architecture	<ul style="list-style-type: none"> <li>• Primary phase</li> </ul>	<ul style="list-style-type: none"> <li>• Secondary phase (may expand to include primary phase)</li> </ul>

Key determinants of scanning system effectiveness	<ul style="list-style-type: none"> <li>• Material type and mass/activity</li> <li>• Source-detector geometry</li> <li>• Presence of benign emitters</li> <li>• Shielding/masking</li> <li>• Vehicle speed</li> <li>• Effectiveness of secondary inspection</li> </ul>	<ul style="list-style-type: none"> <li>• Size and density of package</li> <li>• Presence of other, similar objects</li> <li>• Duration of scan</li> <li>• Operator interpretation of image</li> <li>• Effectiveness of primary screen</li> </ul>
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**Figure 9:** Radiological/Nuclear Smuggling vs. Drug Smuggling

One of the few similarities: both radiological/nuclear smugglers and drug mules are often impoverished individuals for whom the potential gains of engaging in criminal activity represent a powerful inducement.

With respect to radiological/nuclear smuggling specifically:

- Potential gains may be tens to hundreds of thousands of dollars for a single attempt.
- Potential losses may involve several years' imprisonment (however, such sentences are not always served in full).
- Smugglers' average incomes are only a few thousand dollars per year; thus, gains appear large relative to losses and deterrence is difficult.
- Before the mid-2000s, most apprehensions resulted from intelligence operations; smugglers likely knew that their chances of being detected at a border checkpoint were less than 10 percent.
- Subsequent widespread deployment of portal monitors and vans increased the probability of detection at border checkpoints; however, smuggling attempts have continued.
- One or more recent incidents may have been made despite knowledge that scanning systems were probably or certainly present; alternative explanations include lack of prior knowledge, exploitation of coverage gaps, or bribery of border officials.
- Conclusive analysis of these incidents is not possible using only open source data.
- A tentative and very rough estimate is that at least some radiological/nuclear smugglers may not be deterred unless the probability of detection is quite high—perhaps 50 percent or greater.

- Depending on the perceived effectiveness of secondary inspection, deterrence may require near certainty that the material will be scanned in the primary phase and that the system will alarm; the latter stipulation is notoriously difficult in the case of shielded HEU.
- These findings are caveated by the use of open-source information only, the relatively small number of incidents, the high degree of uncertainty in intermediate variables, and the application of decision-making models that have not been validated for this particular population of decision makers.

With respect to drug smuggling at SWB LPOEs,

- Deterrence is difficult ... not only because current scanning rates are low, but also because smugglers use organizational constructs that encourage risk taking, recruit risk-seeking individuals, and react to increased interdiction by adapting their smuggling techniques and/or engaging in more risky behavior to recoup losses.
- It is not possible to develop quantitative estimates of deterrent effects for large-scale DTOs without a more complete picture of their business model(s).
- It is also difficult (using aggregated data) to quantify deterrent effects for the pool of potential drug mules.
- Some existing evidence suggests that increased detection may deter regional smuggling cells, provided that a vehicle's probability of being scanned exceeds 30 percent—far above the current rate.
- Under the current architecture, a very large increase in detection probability would require a significant increase in the general rate of referral to secondary inspection, which would have unacceptable impacts on required resource levels and/or the flow of legitimate commerce.

- New systems under development may allow CBP to scan all vehicles during the pre-primary phase, increasing the probability that a smuggler is referred to secondary inspection without significantly increasing referral rates for innocent vehicles.
- The deterrent effect of these new systems can be predicted and tested, provided that their effectiveness is known, they are deployed to all SWB LPOEs (to minimize the effects of displacement), and they are not susceptible to countermeasures.
- Some of the intermediate variables used to develop these predictions are based on very rough estimates. Moreover, data on deterrent effects is derived from experience with organizations (e.g., Colombian cocaine smugglers) and smuggling routes (e.g., transit through the eastern Caribbean) that may not be generalizable.

Many of the caveats and limitations noted above point to areas for further research and analysis. An example is the need to test behavioral economics models such as CPT on populations of actual and/or potential cross-border smugglers. Widening the scope of analysis to include intelligence and/or law-enforcement sensitive information could also impact some of the above conclusions.

## APPENDIX A: EXTENDED MODEL

### Screening and Scanning

Suppose illicit entries at a checkpoint are screened and scanned, with the probability of detection for a single attempt equal to  $p^1$ . This probability depends on the false negative rate of the scanner (the probability it fails to detect illicit material that is present, denoted  $\alpha$ ) and the scanning rate (the probability that scanning will occur, denoted  $\rho$ ). The form of the relationship is dictated by the screening architecture. Specifically, it is the probability of following any path that leads to the result “apprehended.” For an imaging system used in secondary inspection to detect illicit drugs (cf. Figure 2 of the main body),

$$p^1 = \rho(1 - \alpha)$$

whereas for a radiation portal monitor (cf. Figure 1),

$$p^1 = \rho(1 - \alpha)\sigma_\rho + \rho\alpha\kappa\sigma_\kappa + (1 - \rho)\kappa\sigma_\kappa$$

with  $\kappa$  the rate of referral to secondary in the absence of an alarm, and  $\sigma_\rho$  and  $\sigma_\kappa$  the effectiveness of the secondary inspection given that an alarm has or has not occurred, respectively.

### Deterrence

Given some time unit of interest (a year, a day, etc.), let  $I$  be the number of intentionally illicit entry attempts and  $C$  be the number of attempts that are caught.

Then

$$I = I_0\delta(\alpha, \rho)$$

$$C = p^1I = p^1I_0\delta(\alpha, \rho)$$

where  $I_0$  is the number of illicit attempts at some baseline condition (for example, in the absence of scanning). The expression  $\delta(\alpha, \rho)$  is the “deterrence function”: the probability that an illicit entry is attempted, given scanning with the parameters  $\rho$  and  $\alpha$ .

Measuring the deterrent effects of a scanning system with the parameters  $\rho$  and  $\alpha$  requires the ability to evaluate  $\delta(\alpha, \rho)$ .

### Deterrence Threshold

Let  $p^*$  be the smuggler's estimate of the probability that their contemplated activity will be unsuccessful. (If it consists of a single attempt and smugglers have perfect knowledge regarding the screening and scanning process, failure means that that attempt is detected; that is,  $p^* = p^1$ .) In general, the value of  $p^*$  will depend on the perceived values of  $\alpha$  and  $\rho$ .

For a single decision to smuggle, a deterrence threshold is a value,  $\tau_0$ , such that<sup>62</sup>

$$\begin{aligned}\delta(\alpha, \rho) &= 1 \quad \text{if } p^* < \tau_0 \\ &= 0 \quad \text{otherwise}\end{aligned}$$

For multiple decisions, thresholds lie in the interval  $[\tau_1, \tau_2]$ . Here,  $\delta(\alpha, \rho)$  measures the percentage of cases where smuggling will occur. That is,

$$\begin{aligned}\delta(\alpha, \rho) &= 1 \quad \text{if } p^* \leq \tau_1 \\ \delta(\alpha, \rho) &= 0 \quad \text{if } p^* > \tau_2\end{aligned}$$

and for values of  $p^*$  between  $\tau_1$ , and  $\tau_2$ , some fraction of the group is deterred. That fraction depends on the functional form of  $\delta(\alpha, \rho)$ .

Different forms of  $\delta(\alpha, \rho)$  can be understood by viewing  $\tau$  as a random variable with a density function  $f(\tau)$ . The value of  $\delta(\alpha, \rho)$  is then given by

$$\delta(\alpha, \rho) = 1 - \int_0^{p^*(\alpha, \rho)} f(\tau) d\tau$$

For example, if  $f(\tau)$  is a single valued density function

$$\begin{aligned}f(\tau) &= 1 \quad \text{if } \tau = \tau_0, \\ &= 0 \quad \text{if } \tau \neq \tau_0\end{aligned}$$

then  $\delta(\alpha, \rho)$  is a step function (cf. the case of single decision, above).

If  $\tau$  is uniformly distributed over  $[\tau_1, \tau_2]$

$$\begin{aligned} f(\tau) &= 0 && \text{if } \tau \leq \tau_1, \\ &= 1/(\tau_2 - \tau_1) && \text{if } \tau_1 < \tau \leq \tau_2, \\ &= 0 && \text{if } \tau > \tau_2 \end{aligned}$$

then  $\delta(\alpha, \rho)$  is linear over that interval:<sup>63</sup>

$$\begin{aligned} \delta(\alpha, \rho) &= 1 && \text{if } p^* \leq \tau_1, \\ &= 1 - (p^* - \tau_1) / (\tau_2 - \tau_1) && \text{if } \tau_1 < p^* \leq \tau_2, \\ &= 0 && \text{if } p^* > \tau_2 \end{aligned}$$

If  $\tau$  follows a beta distribution with parameters  $\eta$  and 1 over the interval  $[0, 1]$

$$f(\tau) = \Delta \eta \tau^{\eta-1}$$

then  $\delta$  takes the form of a power function:<sup>64</sup>

$$\delta(\alpha, \rho) = 1 - \Delta (p^*)^\eta$$

and so on. The key point is that *any* form of  $\delta(\alpha, \rho)$  corresponds to a distribution of deterrence thresholds over a specified interval; thus, evaluating  $\delta(\alpha, \rho)$  is equivalent to determining the density  $f(\tau)$ .

## Success and Failure

Because thresholds are defined in terms of smugglers' estimates regarding failure ( $p^*$ ), the meaning of "failure" must be defined in terms of  $\alpha$  and  $\rho$ .

Suppose "success" requires at least  $E$  undetected entries out of  $A$  attempts ( $E \leq A$ ). The values of  $E$  and  $A$  will depend on the nature of the activity and the motivations of the smuggler. For example, a drug mule or opportunistic nuclear smuggler focuses on a single attempt and its resultant reward; therefore,  $E = A = 1$ . A terrorist organization requires only that one of its attempts culminate in undetected entry and subsequent attack; that is,  $E = 1, A \geq 1$ . An ongoing criminal enterprise (for example, a drug trafficking organization) may require that a certain percentage of attempted entries go undetected so that the resulting sales generate sufficient profits; that is,  $E \geq 1, A \geq 1$ , and  $E/A$  greater than some specified value.

For given  $E$  and  $A$ ,

$$p^* = 1 - \sum_{i=E}^A \binom{A}{i} [1 - p^1]^i [p^1]^{A-i}$$

(When  $E = A = 1$ , this expression reduces to  $p^* = p^1$ .)

Since  $p^1$  is defined in terms of  $\alpha$  and  $\rho$ , the above expression completes the linkage: from the values of  $\alpha$  and  $\rho$ , to the resultant value of  $p^1$ , the value of  $p^*$ , and the predicted value of  $\delta(\alpha, \rho)$ , based on the distribution of  $\tau$ .

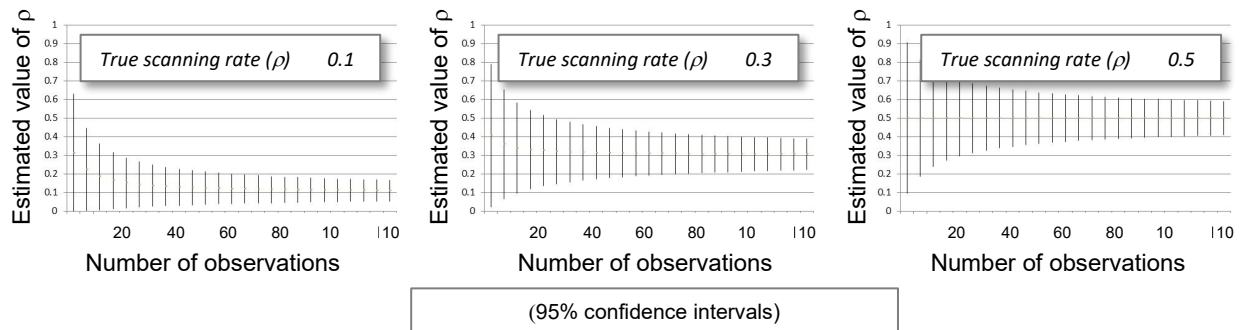
## APPENDIX B: REPEATED OBSERVATIONS

A lone smuggler may approach a checkpoint with only a general sense of the scanning rate. However, a criminal organization can pool many observations to estimate  $\rho$ . If there are  $n$  observations and  $n$  is sufficiently large, an approximate 95 percent confidence interval for  $\rho$  is:

$$\text{Lower bound} = 1 - B_{inv}\left(1 - \frac{0.05}{2}, n - n\rho + 1, n\rho\right)$$

$$\text{Upper bound} = 1 - B_{inv}\left(\frac{0.05}{2}, n - n\rho, n\rho + 1\right)$$

where  $B_{inv}$  is the inverse of the so-called beta cumulative distribution function.<sup>65</sup> Figure 10 shows that  $\rho$  can be estimated to within  $\pm 0.15$  given roughly 40 such observations. Approximately 200 observations suffice to sharpen the estimate to within  $\pm 0.05$ .



**Figure 10:** Estimating the Scanning Rate Based on Repeated Observations

This approach incorporates perception and learning into a closed form, static model. In a dynamic simulation, learning can be modeled explicitly.<sup>66</sup>

## APPENDIX C: DECISION MAKING, RISK, AND UNCERTAINTY

### Rational Choice

The theory of rational choice holds that criminals consider the nature of gains and losses that will result from their actions, estimate the associated probabilities and magnitudes, and decide to commit a crime if the expected benefit outweighs the expected loss. An outstanding example is the seminal work of the

economist Gary Becker,<sup>67</sup> whose economic model of crime revolves around the expected value of benefits and losses.

### **Expected Value Theory (EVT)**

Under EVT, benefits and losses are measured in terms of monetary value.<sup>68</sup> Representing these terms as  $B \geq 0$  and  $P < 0$ , smuggling will occur if

$$[1 - p^*]B + p^*P > 0$$

where  $p^*$  is the perceived probability of failure. The above condition can be rewritten as

$p^* < \tau_0$ , where<sup>69</sup>

$$\tau_0 = B/(B - P)$$

Thus, for example, if the magnitude of punishment  $|P|$  were four times the potential benefit from smuggling ( $P = -4B$ ), a scanning system that resulted in  $p^* > 0.20$  would provide a deterrent. If  $B \gg |P|$  (that is, the benefit is many times the magnitude of the potential punishment), then Equation 17 yields  $\tau_0 \approx 1$  and deterrence is problematic.

### **Expected Utility Theory (EUT)**

By contrast, EUT assumes that  $B$  and  $P$  are evaluated subjectively; that is,

$$\tau_0 = [u(B) - u(0)]/[u(B - P)]$$

where  $u(x)$  is a “utility function” and  $u(0)$  is the utility of doing nothing (i.e., engaging in legitimate activity). To calculate  $\tau_0$ , one must know the form of the function  $u$ .

### **Risk Tolerance**

Under EUT, the function  $u$  can be convex, linear, or concave. If  $u$  is convex ( $u''(x) > 0$ ), then not only do increased gains represent greater utility, the rate of increase grows with larger benefits. Under such conditions, individuals may be willing to engage in an activity for an expected utility that is less than the



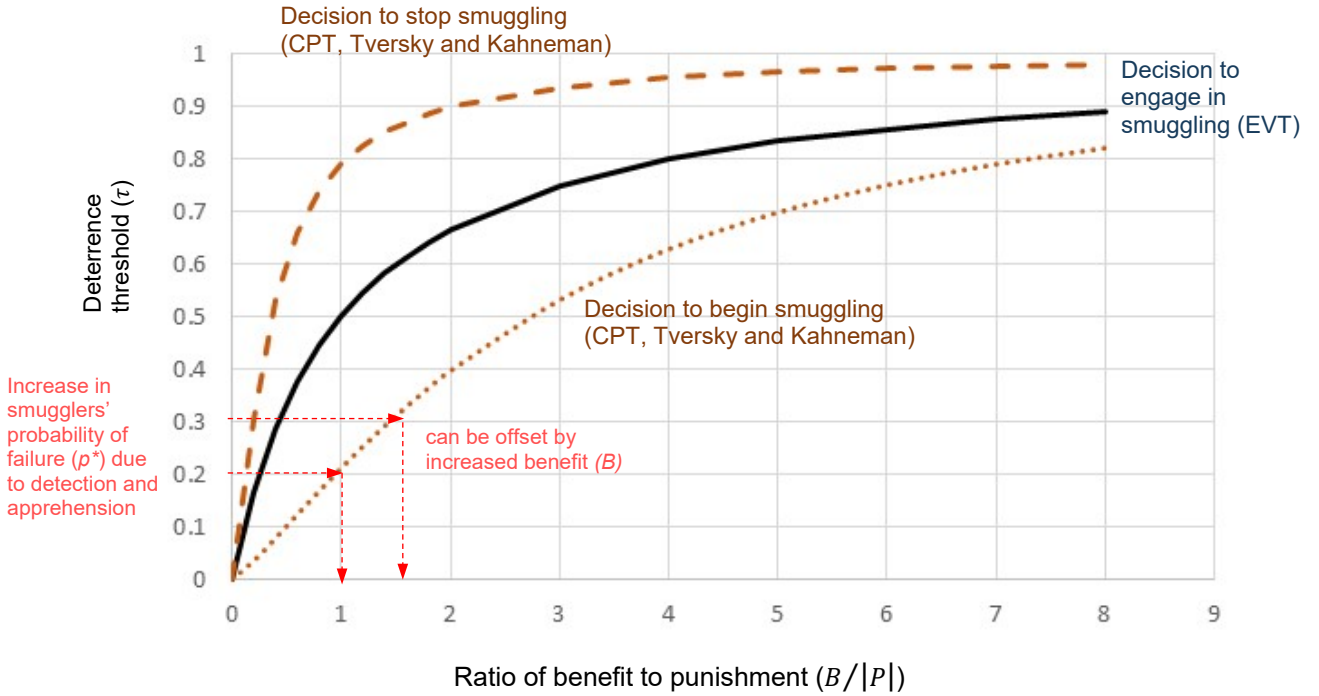
If the form of the functions  $u$ ,  $\pi^+$  and  $\pi^-$  is specified, the threshold  $\tau_0$  can be computed by determining the value of  $p^*$  for which the outcome of the decision to smuggle is zero. (The equation must be solved numerically.)

### “Standard” Version of CPT

Based on empirical data, Kahneman and Tversky arrived at the following:<sup>72</sup>

$$\begin{aligned}
 u(x) &= x^{0.88} && \text{for } x \geq 0 \\
 &= -2.25(-x)^{0.88} && \text{for } x < 0 \\
 \pi^+(p) &= \frac{p^{0.61}}{[p^{0.61} + (1-p)^{0.61}]^{(1/0.61)}} && \text{for } x \geq 0 \\
 \pi^-(p) &= \frac{p^{0.69}}{[p^{0.69} + (1-p)^{0.69}]^{(1/0.69)}} && \text{for } x < 0
 \end{aligned}$$

Figure 11 shows the resulting values of  $\tau_0$  as a function of the ratio  $B/|P|$ . (The comparable predictions under EVT are also shown.) The figure suggests that when the punishment  $P$  is fixed, an increase in  $p^*$  can be overcome (in terms of its deterrent effect) by raising the level of benefit  $B$ . For example, with  $B = 1$ ,  $P = -1$ , CPT predicts that smuggling will be initiated when  $p^* < 0.20$ . If  $p^*$  is increased to 0.30, raising  $B$  to 1.5 restores the inducement to smuggle.



**Figure 11:** Deterrence Threshold as a Function of Benefit and Punishment

Note that while EVT does not distinguish between the decision to start smuggling and the decision to stop, CPT predicts that the latter has a higher deterrence threshold. For the decision to begin smuggling, prospective gains and losses are  $G|R = B$  and  $L|R = P$ . However, for the decision to stop, the prospective gain is the avoidance of punishment and the prospective loss is the foregone benefit; that is,  $G|R = -P$  and  $L|R = -B$ . Since  $u(x) \neq -u(-x)$ , the expected outcome under a given value of  $p^*$  will be different. In other words: decreasing the profits of a smuggling organization by increasing the probability of detection and apprehension changes its reference point: it will likely try to recapture its losses by engaging in more risky behavior.<sup>73</sup>

### Other Theories

Other decision-making theories include rank-dependent utility (RDU) theory (a special case of CPT in which  $\pi^+ = \pi^-$ ), dual theory (a special case of RDU in which  $u(x)$  is constrained to be linear), disappointment aversion theory (a different method of parameterizing  $\pi^+$  and  $\pi^-$ ), and salience theory (a

generalization of CPT in which  $\pi^+$  and  $\pi^-$  may depend explicitly on  $x$  as well as  $p$ ). Including them in the study would not likely change its conclusions.

## APPENDIX D: POTENTIAL DTO RESPONSE

To illustrate the difficulty of quantitative deterrence predictions for large DTOs, consider any starting values of the extended model parameters  $A, E, B, P$  and  $\tau$ , along with the starting value  $p^1 = 0.10$ . (See Appendices A and C for definitions of these and other terms.)

The ratio of gain to loss (in this case, revenue to total cost) corresponds to the DTO's profitability; that is,

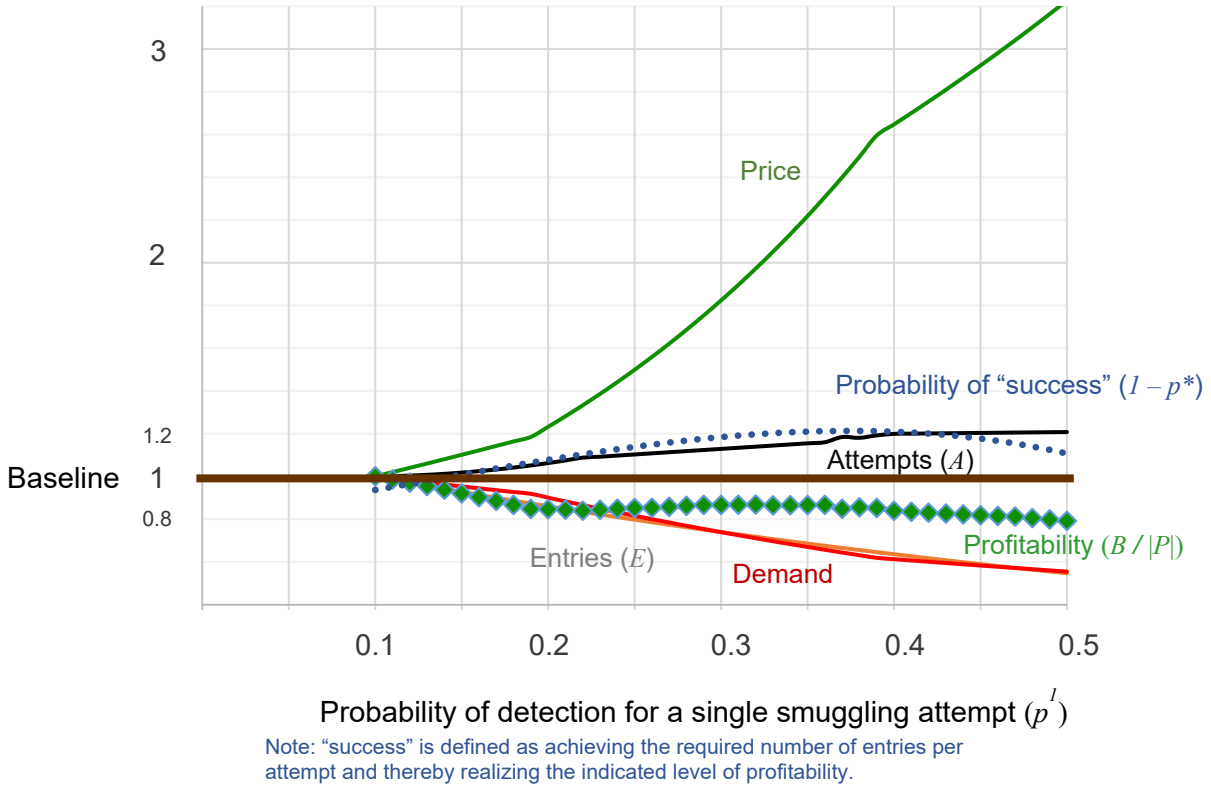
$$\frac{B}{|P|} = \frac{\text{price} \times \min(\text{demand}, E)}{A \times (\text{smuggling cost} + \text{other cost})}$$

where "price" and "cost" are expressed on a per-shipment basis, and "demand" is expressed in equivalent number of shipments.

An increase in scanning rate ( $\Delta\rho$ ) increases both  $p^1$  and  $p^*$ , and therefore raises smuggling costs by necessitating increased payments to mules per Figure 11 in Appendix C. To compensate, the DTO can adjust  $A$  and  $E$  and/or raise the sales price, recognizing that an increase in price will reduce demand:<sup>74</sup>

$$\Delta \text{demand} = (1 - 0.005)^{\ln(1.01)/\ln(\Delta \text{price})}$$

As  $\rho$  increases, there are many possible ways to choose values for  $A, E$ , and sales price such that profitability, as measured by  $B/|P|$ , is maintained. Even with a detection probability  $p^1 = 0.50$ , it is possible to maintain  $B/|P|$  at 80 percent of its baseline value with a near-constant probability of success  $1 - p^*$ . (Figure 12 shows one possible way to achieve this result.) If these outcomes were acceptable to the DTO, there would be no deterrent effects over this range of values for  $p^1$ .



**Figure 12:** Maintaining DTO Profit Margin Under Increased Detection (Example)

*About the Author*

George E. Thompson has over 40 years' experience performing operations analysis in the national security and homeland security domains. From 2004 through 2016, he served as Deputy Director and, for a time, acting Director of the Homeland Security Studies and Analysis Institute, a Federally Funded Research and Development Center sponsored by the Department of Homeland Security (DHS) and operated by ANSER Inc. For the DHS Secretary, Mr. Thompson led an independent analysis of next-generation systems for detecting radiological/nuclear smuggling, and presented the results to Congress. He also led the Department's first formal Analysis of Alternatives, which examined the use of technology to provide situational awareness along the southwest border of the United States. Earlier in his career, Mr. Thompson led a team that performed the first-ever Joint Mission Analysis for the newly-established U.S. Special Operations Command; he also developed supporting analysis tools. He may be reached at [george.thompson@anser.org](mailto:george.thompson@anser.org).

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## NOTES

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- <sup>1</sup> U.S. Customs and Border Protection (CBP) refers to these systems as examples of Non-Intrusive Inspection (NII) technology.
- <sup>2</sup> In its first strategic plan, CBP stated that its NII program aimed to “improve [the] ability to detect *and deter* illicit radiological materials and nuclear devices...” (U.S. Customs and Border Protection, *Protecting America: U.S. CBP 2005-2010 Strategic Plan* (Washington DC: U.S. Customs and Border Protection, 2005), 20, Objective 1.3, emphasis added). More recent testimony states that “improvements in our drug detection technology and targeting capabilities...are critical [to] CBP’s ability to identify *and deter* the entry of dangerous illicit drugs in all operational environments.” *Stop the Importation and Trafficking of Synthetic Analogues Act: Testimony Before the U.S. House of Representatives Judiciary Committee, Subcommittee on Crime, Terrorism, Homeland Security and Investigations*, 115<sup>th</sup> Cong. 1 (2017) (statement of Robert E Perez, CBP Executive Assistant Commissioner, Office of Operations Support), emphasis added.)
- <sup>3</sup> In practice, most radiological/nuclear smuggling has occurred in the former Soviet Union, eastern Europe, and the Black Sea/Transcaucasus regions.
- <sup>4</sup> Most attempts to smuggle illicit drugs into the United States occur at the SWB (Kristine Finklea, *Illicit Drug Flows and Seizures in the United States: What Do We [Not] Know?*, CRS Report No. R-45812 (Washington, DC: Congressional Research Service, 2019), 10, <https://crsreports.congress.gov/product/pdf/R/R45812>).
- <sup>5</sup> “Screening” is the process of separating crossers for the purpose of detecting smuggled items. “Scanning” is the active or passive use of penetrating electromagnetic radiation (X-rays or gamma rays) to determine the contents of a vehicle or container without physically inspecting it.
- <sup>6</sup> For additional details on radiological/nuclear checkpoint screening, see International Atomic Energy Agency, *Nuclear Security Systems and Measures for the Detection of Nuclear and Other Radioactive Material out of Regulatory Control*, Nuclear Security Series, Report No. 21 (Vienna, Austria: 2013), 28-40. Regarding the process used to detect illicit drugs at the U.S. border, see Rebecca Gambler, *Land Ports of Entry: CBP Should Update Policies and Enhance Analysis of Inspections*, GAO 19-658 (Washington, DC: Government Accountability Office, 2019), 10.
- <sup>7</sup> Vitaly Fedchenko and Ian Anthony, *Nuclear Security in the Black Sea Region; Contested Spaces, National Capacities and Multinational Potential*, policy paper no. 49 (Solna, Sweden: Stockholm International Peace Research Institute, 2018), 24 <https://www.sipri.org/publications/2018/sipri-policy-papers/nuclear-security-black-sea-region-contested-spaces-national-capacities-and-multinational-potential> .

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- <sup>8</sup> Patrick Radden Keefe, “Cocaine Incorporated,” *New York Times Magazine*, June 15, 2012, <https://www.nytimes.com/2012/06/17/magazine/how-a-mexican-drug-cartel-makes-its-billions.htm>, quotes a former DEA chief of intelligence: “The goal of these folks is not to [smuggle] drugs...It’s to earn a spendable profit and live to enjoy it.”
- <sup>9</sup> Lyudmila Zaitseva, “Organized Crime, Terrorism and Nuclear Trafficking,” *Strategic Insights*, Vol. 6, No. 5 (August 2007), <https://www.hsdl.org/?view&did=477914>, analyzed some 400 nuclear trafficking incidents that occurred between January 2001 and December 2005. She found 40 that involved a) actual theft (vice claimed theft), b) involvement of more than one individual, and c) evidence of ‘continuing criminal activity’ by these individuals. Phil Williams, “Terrorism, Organized Crime, and WMD Smuggling: Challenge and Response,” *Strategic Insights*, Vol. 6, No. 5 (August 2007) <http://edocs.nps.edu/npspubs/institutional/newsletters/strategic%20insight/2007/williamsAug07.pdf>, describes smuggling techniques used by criminal groups; cf. the definition of “high-end” smuggling in Rensselaer Lee, “Nuclear Smuggling: Patterns and Responses,” *Parameters: U.S. Army War College Quarterly*, 103, (Spring 2003), <http://carlisle-www.army.mil/usawc/Parameters/03spring/lee.pdf>.
- <sup>10</sup> Based on 150,000 attempts per year and six to nine major DTOs.
- <sup>11</sup> Fedchenko and Anthony, *Nuclear Security in the Black Sea Region...*, 24. A review of the literature on radioactive and dual-use smuggling found no absolute consensus, but noted that in interviews with smugglers and brokers, “financial motives seem to dominate.” Egle Murauskaitė, “Nuclear Smuggling and Threats to Lithuanian Security.” *Lithuanian Annual Strategic Review*, Vol. 14, (2015) : 181–96, [https://www.researchgate.net/publication/311521728\\_Nuclear\\_Smuggling\\_and\\_Threats\\_to\\_Lithuanian\\_Security](https://www.researchgate.net/publication/311521728_Nuclear_Smuggling_and_Threats_to_Lithuanian_Security). Note that this description applies to those who are carrying the smuggled material, not to buyers or end-users, about whose motives little or no information is available in the open literature. Lyudmila Zaitseva and Kevin Hand, “Nuclear Smuggling Chains: Suppliers, Intermediaries, and End-Users,” *American Behavioral Scientist*, Vol. 46, No. 6, (2003): 822–44, <https://doi.org/10.1177/0002764202239177>. Lee, at p. 109, states that “The actual design and extent of the illicit market for nuclear goods are largely a mystery.”
- <sup>12</sup> See, for example, Lawrence Scott Sheets, “A Smuggler’s Story,” *The Atlantic*, April 2008, <https://www.theatlantic.com/magazine/archive/2008/04/a-smuggler-s-story/306736/>; Alex P. Schmid and Charlotte Spencer-Smith, “Illicit Radiological and Nuclear Trafficking, Smuggling and Security Incidents in the Black Sea Region since the Fall of the Iron Curtain – an Open Source Inventory,” *Perspectives on Terrorism*, Vol. 6, No. 2 (2012), <http://www.terrorismanalysts.com/pt/index.php/pot/article/view/schmid-illicit-radiological/html>; and Badalova, Aygun, “Alarming Trail of Armenia’s Nuclear Ambitions,” *Energy Central News*, May 10, 2016, <https://www.energycentral.com/news/alarming-trail-armenias-nuclear-ambitions>.

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- <sup>13</sup> Maia Edilashvili, *Georgia: Nuclear Smuggling Cases Raise Concern*, EurasiaNet, July 8, 2016, <https://eurasianet.org/georgia-nuclear-smuggling-cases-raise-concern>, reports that “poverty appears to be a factor in [these] smuggling cases”: one apprehended suspect “would have accepted whatever he had been paid” to help smuggle uranium. CDRF Global, *Building Nuclear Forensics Capacity in Armenia*, September 15, 2017, <https://www.crdfglobal.org/insights/building-nuclear-forensics-capacity-armenia>, states that “the majority of [suspects] were ‘pensioners in their mid-70s’ who ‘needed more money to live on.’”
- <sup>14</sup> “GDP Per Capita (Current US \$),” World Bank, [https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?most\\_recent\\_value\\_desc=false](https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?most_recent_value_desc=false), accessed January 28, 2020; Simon Shuster, “Inside the Uranium Underworld: Dark Secrets, Dirty Bombs,” *Time*, April 10, 2017, <https://time.com/4728293/uranium-underworld-dark-secrets-dirty-bombs/>.
- <sup>15</sup> Zaitseva laments the “lack of follow-up reporting” on this point. In support of the figures given, see “Convicted HEU Smuggler Released in Georgia After Serving Prison Term,” Nuclear Threat Initiative, March 1, 2007, <https://www.nti.org/analysis/articles/heu-smuggler-released-georgia/>; Luke Heighton, “Armenia and Georgia Foil Latest Uranium Smuggling Plot,” *Open Democracy*, November 10, 2010, <https://www.opendemocracy.net/en/opensecurity/101110/>; and the examples mentioned by Schmid and Spencer-Smith.
- <sup>16</sup> David Bjerk and Caleb Mason, *The Market for Mules: Risk and Compensation of Cross-Border Drug Couriers*, Discussion Paper No. 8224 (Bonn, Germany: Institute for the Study of Labor, 2014), <http://ftp.iza.org/dp8224.pdf>.
- <sup>17</sup> Bjerk and Mason, *The Market for Mules*, 2; Kristina Davis, “Promises of Riches, Leniency, Lure Tens into Smuggling Drugs,” *San Diego Tribune*, July 15, 2018, <https://www.sandiegouniontribune.com/news/courts/sd-me-teen-smuggling-20180706-story.html>.
- <sup>18</sup> Kelli D. Tomlinson, “An Examination of Deterrence Theory—Where Do We Stand?” *Federal Probation*, Vol. 80, No. 3 (December 2016), [https://www.uscourts.gov/sites/default/files/80\\_3\\_4\\_0.pdf](https://www.uscourts.gov/sites/default/files/80_3_4_0.pdf), 33-38.
- <sup>19</sup> Nuclear Threat Initiative, “The CNS Global Incidents and Trafficking Database,” October 4, 2019, <https://www.nti.org/analysis/articles/cns-global-incidents-and-trafficking-database/> (accessed January 20, 2020).
- <sup>20</sup> Nuclear Threat Initiative, “NIS Nuclear Trafficking Collection,” February 1, 2013, <https://www.nti.org/analysis/reports/nis-nuclear-trafficking-database/> (accessed January 20, 2020).
- <sup>21</sup> In addition to Schmid and Spencer-Smith, see William C. Potter and Elena Sokova, “Illicit Nuclear Trafficking in the NIS: What’s New? What’s True?” *The Nonproliferation Review* (Summer, 2002), 112-120; and Mohtadi, Hamid and Antu Murshid, *A Global Chronology of Incidents of Chemical, Biological, Radioactive and Nuclear Attacks: 1950-2005*, (Saint

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Paul, MN: National Center for Food Protection and Defense, July 7, 2006),

<https://pdfs.semanticscholar.org/122d/89e8e4eca042baedddd5d40f586c1ced88ce.pdf>.

- <sup>22</sup> Peter Beck, et al., “ITRAP—International Laboratory and Field Test Site Exercise for Radiation Detection Instruments and Monitoring Systems at Border Crossings,” IAEA-CN-86/2P, in *Proceedings: International conference on security of material; measures to prevent, intercept and respond to illicit uses of nuclear material and radioactive sources* (Stockholm, Sweden: International Atomic Energy Agency, May 7-11, 2001), [https://inis.iaea.org/collection/NCLCollectionStore/\\_Public/32/057/32057759.pdf?r=1&r=1](https://inis.iaea.org/collection/NCLCollectionStore/_Public/32/057/32057759.pdf?r=1&r=1), pp. 535-549; Jones, Gary L., *U.S. Efforts to Help Other Countries Combat Nuclear Smuggling Need Strengthened Coordination and Planning*, GAO 02-426 (Washington, DC: U.S. Government Accountability Office, 2002).
- <sup>23</sup> Jason Carter Brock, *NNSA Nuclear Smuggling Detection and Deterrence*, Report No. LA-UR-16-27700 (Los Alamos, NM: Los Alamos National Laboratory, 2016), <https://permalink.lanl.gov/object/tr?what=info:lanl-repo/lareport/LA-UR-16-27700>; David C. Trimble, *Combating Nuclear Smuggling: NNSA’s Detection and Deterrence Program is Addressing Challenges but Should Improve Its Program Plan*, GAO 16-460 (Washington DC: U.S. Government Accountability Office, 2016), <https://www.gao.gov/assets/680/677895.pdf>; Executive Office of the President, Office of the Press Secretary, “Nuclear Security Summit 2016 - Highlights from National Progress Reports,” April 4, 2016, <https://obamawhitehouse.archives.gov/the-press-office/2016/04/04/nuclear-security-summit-2016-highlights-national-progress-reports> (accessed January 20, 2020); Oak Ridge National Laboratory, *Nuclear Smuggling Detection and Deterrence; FY 2018 Data Analysis Annual Report*, Report No. ORNL/SPR-2019/1087 (Oak Ridge, TN: Oak Ridge National Laboratory, 2019).
- <sup>24</sup> Alexander Glaser, “Detection of Special Nuclear Materials,” (lecture, Princeton University, Princeton, NJ, April 16, 2007), [http://www.princeton.edu/~aglaser/lecture2007\\_detection.pdf](http://www.princeton.edu/~aglaser/lecture2007_detection.pdf); Thomas B. Cochran, and Matthew G. McKinzie, “Detecting Nuclear Smuggling,” *Scientific American*, Vol. 298, No. 4, April 2008, 98-102; Matthew Bunn, et al., *Nuclear Terrorism: Continuous Improvement or Dangerous Decline?* (Cambridge, MA: Harvard University, Belford Center for Science and International Affairs, 2016), <https://www.belfercenter.org/sites/default/files/legacy/files/PreventingNuclearTerrorism-Web.pdf>; Eric P. Rubenstein, *Detection of Radioactivity in Transit Stations*, Transit IDEA Project 42 (Washington, DC: National Academies Transportation Research Board, 2006), [http://onlinepubs.trb.org/onlinepubs/archive/studies/idea/finalreports/transit/Transit42\\_Final\\_Report.pdf](http://onlinepubs.trb.org/onlinepubs/archive/studies/idea/finalreports/transit/Transit42_Final_Report.pdf).
- <sup>25</sup> Diana Maurer, *Combating Nuclear Smuggling: Risk-Informed Covert Assessments and Oversight of Corrective Actions Could Strengthen Capabilities at the Border*, GAO 14-826 (Washington, DC: U.S. Government Accountability Office, 2014).
- <sup>26</sup> Jones, *U.S. Efforts to Help Other Countries Combat Nuclear Smuggling Need Strengthened Coordination and Planning*, 24.

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- <sup>27</sup> The bribing of a Georgian border guard is described in Michael Bronner, *100 Grams (and Counting...); Notes from the Nuclear Underworld*, (Cambridge, MA: Harvard University, Belfer Center for Science and International Affairs, 2008), <https://www.belfercenter.org/sites/default/files/files/publication/100-Grams-Final-Color.pdf>. Cases #2015441 and #2018190 in the CNS database involve discontinued checkpoints: one at Jarovce, Slovakia (now within the Schengen Zone); the other, on the Russia-Kazakhstan border (now within the Eurasian Economic Union (EAEU) and checked only randomly by mobile units, per Yeliseyev, Andrei, *The Eurasian Economic Union: Expectations, Challenges, and Achievements*, Policy Paper No. 10 (Washington, DC: The German Marshall Fund of the United States, 2019), <http://www.gmfus.org/sites/default/files/publications/pdf/Eurasian%20Economic%20Union.pdf>).
- <sup>28</sup> Kazinform International News Agency, *USA and Kazakhstan strengthen coop [sic] against illegal transportation of nuclear materials*, October 30, 2009, [https://www.inform.kz/en/usa-and-kazakhstan-strengthen-coop-against-illegal-transportation-of-nuclear-materials\\_a2208638](https://www.inform.kz/en/usa-and-kazakhstan-strengthen-coop-against-illegal-transportation-of-nuclear-materials_a2208638). Cases labeled 44-46 in the text are described by Schmid and Spencer-Smith. Regarding the case labeled 47 see Blake, Heidi 2011, “WikiLeaks: Uranium Bricks and Radioactive Trains Among Nuclear Terror Scares,” *The Telegraph*, February 2, 2011, <https://www.telegraph.co.uk/news/worldnews/wikileaks/8296982/WikiLeaks-uranium-bricks-and-radioactive-trains-among-nuclear-terror-scares.html>.
- <sup>29</sup> These incidents are cases #2012185, #2012280, #2012293, #2015454, and #2016578 in the CNS database. “Monthly salaries for border-control officers [in Georgia]...increased from 350 laris (\$165) in 2010 to an average of 1,000 laris (\$472) [in 2016]...to counter the risk of corruption within the border service”; “Georgia arrests suspected smugglers of radioactive materials,” *Associated Press*, January 11, 2016, <https://www.businessinsider.com/ap-georgia-arrests-suspected-smugglers-of-radioactive-materials-2016-1>).
- <sup>30</sup> Trimble, *Combating Nuclear Smuggling: NNSA’s Detection and Deterrence Program is Addressing Challenges but Should Improve Its Program Plan*, 23; Matthew Bunn, et al., “Don’t weaken our defenses against nuclear smuggling,” *The Hill*, May 20, 2015, <https://thehill.com/blogs/congress-blog/homeland-security/242566-dont-weaken-our-defenses-against-nuclear-smuggling>, describes one such incident. It is not clear whether this is the case labeled 55 in the text (#2012280 in the CNS database).
- <sup>31</sup> These figures should be viewed as approximate: thresholds may be lower if smugglers feel less than certain to realize the prospective gain following a successful crossing, or weigh the threat of punishment more heavily than the value of lost income. Thresholds may be higher if smugglers believe they can avoid punishment even if caught.
- <sup>32</sup> The preceding paragraphs imply that  $\tau_1 \leq \sigma_\rho$  and  $\tau_1 \cong 0.40$ ; similarly, that  $\tau_2 \geq \sigma_\rho$  and  $\tau_2 \cong 0.70$ . Given the uncertainty in the specific values 0.40 and 0.70, the expressions given for the endpoints of the interval  $[\tau_1, \tau_2]$  may be regarded as conservative, in that they result in the widest interval for a given value of  $\sigma_\rho$ . To take an admittedly extreme example, if  $\sigma_\rho$

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were known to be close to 1.00 and at least one of the cases shown in Figure 4 involved prior knowledge that the scanner was present, the implication would be that even the near certainty of being caught is not sufficient to deter some attempts and therefore  $\tau_2 \cong 1.00$ .

- <sup>33</sup> Author's estimate based on data from U.S. Customs and Border Protection, "CBP Enforcement Statistics, FY 2019," <https://www.cbp.gov/newsroom/stats/cbp-enforcement-statistics-fy2019>, accessed January 3, 2020, and "CBP Strategy to Combat Opioids," <https://www.cbp.gov/sites/default/files/assets/documents/2019-Mar/opioid-factsheet.pdf>, accessed January 3, 2020); and the U.S. Drug Enforcement Administration (*2018 National Drug Threat Assessment*, Report No. DEA-DCT-DIR-032-18; *2017 National Drug Threat Assessment*, Report No. DEA-DCT-DIR-040-17; and *2016 National Drug Threat Assessment; Summary*, Report No. DEA-DCT-DIR-001-17 (Washington, DC: U.S. Drug Enforcement Administration).
- <sup>34</sup> Abt Associates, *Estimation of Cocaine Availability, 1996-2000* (Washington, DC: U.S. Office of National Drug Control Policy (ONDCP), Office of Planning and Budget, 2002), <https://www.hsdl.org/?abstract&did=3441>, 13; ONDCP, *Drug Availability Estimates in the United States*, (Washington DC: U.S. Office of National Drug Control Policy, 2012), [https://obamawhitehouse.archives.gov/sites/default/files/page/files/daeus\\_report\\_final\\_1.pdf](https://obamawhitehouse.archives.gov/sites/default/files/page/files/daeus_report_final_1.pdf) (accessed January 20, 2020), 48-50, 69-70, 89, and 105-6.
- <sup>35</sup> See "San Diego's Border Busts," *NBC Bay Area*, December 3, 2019, <https://www.nbcbayarea.com/news/california/border-busts/71490/> and DEA annual threat assessment reports.
- <sup>36</sup> Luke Morris, "With Help of Magnets, Drug Smugglers Are Turning Unsuspecting Border Crossers into Mules," *Dallas Morning News*, January 22, 2015, <https://www.dallasnews.com/news/2015/01/23/with-help-of-magnets-drug-smugglers-are-turning-unsuspecting-border-crossers-into-mules/>; Julian Resendiz, "People Unknowingly Driving Drugs Across the Border, CBP Sources Say," *Border Report*, October 2, 2019, <https://www.borderreport.com/hot-topics/border-crime/people-unknowingly-driving-drugs-across-the-border-cbp-sources-say/>.
- <sup>37</sup> Note that screening effectiveness is a conditional probability: the probability that the vehicle is referred to secondary inspection *given that it is carrying illicit drugs*. The general referral rate is unconditional.
- <sup>38</sup> Current referral rates per Sari Horwitz and Scott Highman, "The Flow of Fentanyl: In the Mail, Over the Border," *Washington Post*, August 23, 2019, <https://www.washingtonpost.com/investigations/2019/08/23/fentanyl-flowed-through-us-postal-service-vehicles-crossing-southern-border/?arc404=true>; the estimate of 4,000 scans per narcotics seizure is based on data in *Trade and Commerce at U.S. Ports of Entry: Testimony Before the U.S. Senate Committee on Finance, Subcommittee on International Trade, Customs and Global Competitiveness*, 115<sup>th</sup> Cong. 2 (2018) (statement of Kevin McAleenan, CBP Commissioner). Assuming that approximately one vehicle per 600 is carrying illicit drugs—based on 150,000 attempts (see text and notes 31-32) per 90 million total crossings "North American Transportation Statistics..." U.S. Department of Transportation, Bureau of Transportation Statistics (BTS), updated September 8, 2017,

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[american-transportation-statistics-almost-93-million-personal-vehicles-entered-united](#))—and that approximately 10 percent of all loads are large enough to be readily detectable by imaging systems (approximately 2,000 seizures per year from imagery, per McAleenan, with a majority, 1,500, assumed to occur at SWB LPOEs), a random selection strategy would yield one seizure per 6,000 scans, vice 4,000.

- <sup>39</sup> Mary Layne, et al., *Measuring the Deterrent Effect of Enforcement Operations on Drug Smuggling, 1991-1999* (Washington, DC: Abt Associates, 2001), 13, 16, [https://www.abtassociates.com/sites/default/files/2019-04/measure\\_deter\\_effct.pdf](https://www.abtassociates.com/sites/default/files/2019-04/measure_deter_effct.pdf); Scott H. Decker and Margaret T. Chapman, *Drug Smugglers on Drug Smuggling: Lessons from the Inside*, (Philadelphia, PA: Temple University Press, 2008).
- <sup>40</sup> For example, Rebecca Koslover, et al., *A Market Survey on Contraband Detection Technologies*, Document 250685 (Washington, DC: National Criminal Justice Reference Service, 2017), <https://www.ncjrs.gov/pdffiles1/nij/grants/250685.pdf> contains almost no such information.
- <sup>41</sup> Gambler, *Land Ports of Entry: CBP Should Update Policies and Enhance Analysis of Inspections*, p.28.
- <sup>42</sup> Victor Orphan, et al., *Advanced Cargo Container Scanning Technology Development*, accessed January 22, 2020, <https://pdfs.semanticscholar.org/6777/98accbdb897fb95cd132e71a6ab9b540c64c.pdf>.
- <sup>43</sup> Author’s analysis of U.S. Department of Transportation, BTS, “Border Crossing Entry Data; Annual Data,” <https://explore.dot.gov/views/BorderCrossingData/Annual?:isGuestRedirectFromVizportal=y&:embed=y>, accessed January 8, 2020.
- <sup>44</sup> Julian Resendiz, “Border Crossings to Get More High-Tech Inspection Devices in 2020,” *Border Report*, December 31, 2019, <https://www.borderreport.com/hot-topics/trade/border-crossings-to-get-more-high-tech-inspection-devices-in-2020/>.
- <sup>45</sup> DEA, *2018 National Drug Threat Assessment*, 97-98; June S. Beittel, *Mexico: Organized Crime and Drug Trafficking Organizations*, CRS Report No. R41576, version 39 (Washington, DC: Congressional Research Service, 2019), <https://crsreports.congress.gov/search/#/?termsToSearch=41576&orderBy=Relevance>, 11, 14-27.
- <sup>46</sup> Robert W. Kurrle, Jr., “The Effective Business Practices of Mexican Drug Trafficking Organizations,” (master’s thesis, U.S. Naval Postgraduate School, 2013), <https://pdfs.semanticscholar.org/b498/74e4114c63fe4c0b0c598c66d61c1b308c92.pdf>, 41-43.
- <sup>47</sup> Kurrle, “The Effective Business Practices of Mexican Drug Trafficking Organizations,” 60; Patrick Keefe, “Cocaine Incorporated,” *New York Times Magazine*, June 15, 2012, <https://www.nytimes.com/2012/06/17/magazine/how-a-mexican-drug-cartel-makes-its-billions.htm>.
- <sup>48</sup> Monica Medel, et al., “Mexico's Drug Networks: Modeling The Smuggling Routes Towards the United States,” *Applied Geography* Vol. 60 (2015): 240-247,

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- [https://www.researchgate.net/publication/271528759\\_Mexico's\\_drug\\_networks\\_Modeling\\_the\\_smuggling\\_routes\\_towards\\_the\\_United\\_States](https://www.researchgate.net/publication/271528759_Mexico's_drug_networks_Modeling_the_smuggling_routes_towards_the_United_States), pp. 240-247; Ying Che and Bruce Benson, “Drug Trafficking Wars: Enforcement Versus Smugglers and Smugglers Versus Smugglers,” *Journal of Drug Issues*, n.d. (preprint, 2013), <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.960.8663&rep=rep1&type=pdf>, 18.
- <sup>49</sup> Rodrigo Nieto-Gomez, “The Geopolitics of Clandestine Innovation in the Drug Business...,” in *The “New” Face of Transnational Crime Organizations (TCOs)...*, Ben Riley and Kathleen Kiernan (eds.) (2013): 153-158, <https://www.hsdl.org/?view&did=733208>, describes DTOs as “deviant entrepreneurs” using illicit venture capital to fund the development of innovative smuggling technologies.
- <sup>50</sup> Cecilia Farfán-Méndez, “The Structure of Drug Trafficking Organizations and Money Laundering Practices: A Risk Appetite Hypothesis,” *Journal of Illicit Economics and Development*, Vol. 1, No. 3 (2019): 294-311, <http://doi.org/10.31389/jied.1>; Jonathan P. Caulkins, J and Robert J. MacCoun, “Limited Rationality and the Limits of Supply Reduction,” (working paper, University of California, Berkeley, Center for the Study of Law and Society Jurisprudence and Social Policy Program, 2003), <https://escholarship.org/uc/item/0t79b8n7>; Che and Benson, “Drug Trafficking Wars,” 19.
- <sup>51</sup> José Miguel Insulza, *The Drug Problem in the Americas: Studies; The Economics of Drug Trafficking*, (Washington, DC: Organization of American States, 2013), 24, [http://www.cicad.oas.org/Main/Template.asp?File=/drogas/elinforme/default\\_eng.asp](http://www.cicad.oas.org/Main/Template.asp?File=/drogas/elinforme/default_eng.asp), notes that Mexican authorities have seized accounting books from some regional smuggling cells, but not from major DTOs.
- <sup>52</sup> Deborah Feyerick, et al., “Drug Smugglers Becoming More Creative, U.S. agents Say,” *CNN*, April 16, 2009, <https://www.cnn.com/2009/CRIME/04/16/creative.drug.smugglers/>, quotes a former DEA chief of global enforcement operations: “They’ll line up 10 loads, and if you pick off two or three, well, that’s the cost of doing business, ‘I got seven across.’ So it’s that shotgun mentality.”
- <sup>53</sup> Barry D. Crane, *Deterrence Effects of Operation Frontier Shield*, Paper P-3460 (Alexandria, VA: Institute for Defense Analyses, 1999), iii,-5, <https://apps.dtic.mil/dtic/tr/fulltext/u2/a362838.pdf>; Mary Layne et al., *Measuring the Deterrent Effect of Enforcement Operations on Drug Smuggling, 1991–1999*. Abt Associates, Washington, D.C., 16, [https://www.abtassociates.com/sites/default/files/2019-04/measure\\_deter\\_effct.pdf](https://www.abtassociates.com/sites/default/files/2019-04/measure_deter_effct.pdf). Note that these studies were based on the activities of cocaine and marijuana smugglers operating in the eastern Caribbean; smuggling patterns have shifted significantly since that time.
- <sup>54</sup> Crane provides no explicit rationale for an upper limit of 1.0. Presumably, it is based on the statement (drawn from interviews) that absolute deterrence would require seizure of four consecutive loads—which is very unlikely without an extremely high probability of detection.

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- <sup>55</sup> Leandra Bernstein, “Vehicle Scanning Technology at the Border Is About to Ruin The Drug Trade,” *NBC Montana*, August 29, 2019, <https://nbcmontana.com/news/nation-world/vehicle-scanning-technology-at-the-border-is-about-to-ruin-the-drug-trade>; Cal Biesecker, “Viken Introduces Under Vehicle Scanner; CBP Plans Evaluation,” *Defense Daily*, November 12, 2019, <https://www.defensedaily.com/viken-introduces-vehicle-scanner-cbp-plans-evaluation/homeland-security/>; Resendiz, “Border Crossings to Get More High-tech Inspection Devices in 2020.”
- <sup>56</sup> Note that the horizontal axis represents the *true* value of pre-primary scanning effectiveness ( $\rho_P$ ) whereas the previous figure used the *perceived* effectiveness of the primary screen. Smuggler underestimation of  $\rho_P$  would affect both attempts and seizures.
- <sup>57</sup> That is, \$12,490 (“2019 Poverty Guidelines,” U.S. Department of Health and Human Services, Office of the Assistant Secretary for Planning and Evaluation, <https://aspe.hhs.gov/2019-poverty-guidelines>, accessed January 21, 2020).
- <sup>58</sup> Justin Rohrlich and Hanna Kozłowska, “Drug Traffickers Are Recruiting Smugglers on Facebook,” *Quartz*, August 1, 2019, <https://qz.com/1680134/facebook-ads-are-being-used-to-recruit-drug-smugglers/>.
- <sup>59</sup> Bjerk and Mason, *The Market for Mules*.
- <sup>60</sup> Kristina Davis, “Promises of Riches, Leniency, Lure Teens into Smuggling Drugs,” *San Diego Tribune*, July 15, 2018, <https://www.sandiegouniontribune.com/news/courts/sd-me-teen-smuggling-20180706-story.html>.
- <sup>61</sup> Che and Benson, “Drug Trafficking Wars,” 17 and 27 (note 27); Francisco Fajardo, “More Teens Being Recruited to Smuggle Drugs into U.S.,” *NBC San Diego*, July 27, 2018, <https://www.nbcsandiego.com/news/local/more-teens-being-recruited-to-smuggle-drugs-into-us/174640/>.
- <sup>62</sup> The notion of comparing failure probability to a threshold is basic and widely used, both in closed-form models and game-theoretic frameworks. Examples include studies of airline passenger screening (Susan E. Martonosi and Arnold Barnett, “How Effective is Security Screening of Airline Passengers?” *Interfaces*, Vol. 36, No. 6 (2006), <https://pubsonline.informs.org/doi/abs/10.1287/inte.1060.0231?journalCode=inte>, 545-552); nuclear smuggling (Jason Merrick and Laura McLay, “Is Screening Cargo Containers for Smuggled Nuclear Threats Worthwhile?” *Decision Analysis*, Vol. 7, No. 2 (June 2010), <https://pdfs.semanticscholar.org/cd2b/a4147e0078e96121f4b3569d1e53bdb077e8.pdf>, 155-171); critical infrastructure protection (Tacquechel, Eric F. and Ted G. Lewis, “More Options for Quantifying Deterrence and Reducing Critical Infrastructure Risk: Cognitive Biases,” *Homeland Security Affairs*, Volume 12 (September 2016), <https://www.hsaj.org/articles/12007>); terrorism (Vicki Bier and Naraphorn Haphuriwat, “Analytical Method to Identify the Number of Containers to Inspect at U.S. Ports to Deter Terrorist Attacks,” *Annals of Operations Research*, Vol. 187, No. 1 (2011), [https://create.usc.edu/sites/default/files/publications/analyticalmethodtoidentifythenumberofcontainerstoinspect\\_0.pdf](https://create.usc.edu/sites/default/files/publications/analyticalmethodtoidentifythenumberofcontainerstoinspect_0.pdf), 137-

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158); highway safety enforcement (Jan Eeckhoutet al. , *Estimating Deterrence Effects Using Random Crackdowns; Theory and Evidence*, December 2004,

[https://www.researchgate.net/publication/228867771\\_Estimating\\_deterrence\\_effects\\_using\\_random\\_crackdowns\\_theory\\_and\\_evidence](https://www.researchgate.net/publication/228867771_Estimating_deterrence_effects_using_random_crackdowns_theory_and_evidence)); drug smuggling (Nicholas Magliocca, et al., “Modeling Cocaine Traffickers and Counterdrug Interdiction Forces as A Complex Adaptive System,” *Proceedings of the National Academy of Sciences*, Vol. 116, No. 16 (April 2019), 7784-7792, <https://doi.org/10.1073/pnas.1812459116>); and a wide range of criminal behavior in general (Aaron Chalfin and Justin McCrary, “Criminal Deterrence: A Review of the Literature,” *Journal of Economic Literature*, Vol. 55, No. 1 (2017), 5-48, [https://eml.berkeley.edu/~jmccrary/chalfin\\_mccrary2017.pdf](https://eml.berkeley.edu/~jmccrary/chalfin_mccrary2017.pdf)). In “Drug Trafficking Wars,” Che and Benson, at p. 14, point out that “there is not likely to be a specific ‘tipping point’ ... that deters all offenders,” hence the need to consider a range of threshold values.

<sup>63</sup> For example, Crane, *Deterrence Effects...*

<sup>64</sup> This form appears in Sheldon H. Jacobson, et al., “Assessing the Impact of Deterrence on Aviation Checked Baggage Screening Strategies,” *Int. J. Risk Assessment and Management*, Vol. 5, No. 1 (2005), 1-15, <https://www.environmental-expert.com/Files/6471/articles/6297/f511110976824123.pdf>.

<sup>65</sup> Richard Kohout, et al., *Airport Employee Screening Analysis*, publication RP15-15-02 (Falls Church, VA: ANSER Inc., Homeland Security Studies and Analysis Institute, 2015). In mathematical terms,  $B_{inv}(p, a, b)$  is the value  $x$  for which

$$\frac{\int_0^x t^{a-1}(1-t)^{b-1} dt}{\int_0^1 t^{a-1}(1-t)^{b-1} dt} = p.$$

<sup>66</sup> See, for example, Magliocca, “Modeling cocaine traffickers...”

<sup>67</sup> See, for example, Gary S. Becker, “Crime and Punishment; An Economic Approach,” *Journal of Political Economy*, Vol. 78 (1968), 189-217, [https://www.researchgate.net/publication/24104445\\_The\\_Market\\_for\\_Illegal\\_Goods\\_The\\_Case\\_of\\_Drugs](https://www.researchgate.net/publication/24104445_The_Market_for_Illegal_Goods_The_Case_of_Drugs). For a concise exposition and review of the related body of work, see Chalfin and McCrary, “Criminal Deterrence...”, 7ff, 5–48.

<sup>68</sup> This condition requires that all gains and losses be monetizable. The term  $P$  is generally held to include the loss of current and future legal income; however, it is difficult to determine how individuals monetize other aspects of punishment.

<sup>69</sup> This relationship appears in different forms in the literature. For example, some authors define  $B$  as the expected benefit, rather than the potential benefit, and write  $\tau_0 = B/(-P)$ . Moreover, some authors define  $P$  not as the potential punishment resulting from detection/apprehension, but the potential punishment resulting from detection/apprehension *and conviction*. In this work, the emphasis is on detection, and  $P$  is taken as the product of two variables: the probability that punishment will occur if an individual is detected and apprehended (how likely is it that the smuggler, once detected and apprehended, will be

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convicted of a crime?) and the magnitude of such punishment (what will be the resulting sentence; how much of it will actually be served?). These two variables are commonly termed the “certainty” and “severity” of punishment.

<sup>70</sup> For a more complete (and graphical) explanation, see Che and Benson, “Drug Trafficking Wars,” 5-8.

<sup>71</sup> Amos Tversky and Daniel Kahneman, “Advances in Prospect Theory: Cumulative Representation of Uncertainty,” *Journal of Risk and Uncertainty*, Vol. 5 (1992), 297-323, [http://cemi.ehess.fr/docannexe/file/2780/tversky\\_kahneman\\_advances.pdf](http://cemi.ehess.fr/docannexe/file/2780/tversky_kahneman_advances.pdf).

Note that CPT, like EVT, assumes gains and losses are monetizable.

<sup>72</sup> Tversky and Kahneman, “Advances in Prospect Theory,” 310-312. Glenn W. Harrison, and J. Todd Swarthout, *Cumulative Prospect Theory in the Laboratory: A Reconsideration*, July 2016, [https://cear.gsu.edu/files/2016/06/WP\\_2016\\_05\\_Cumulative-Prospect-Theory-in-the-Laboratory-A-Reconsideration\\_MAR-2017.pdf](https://cear.gsu.edu/files/2016/06/WP_2016_05_Cumulative-Prospect-Theory-in-the-Laboratory-A-Reconsideration_MAR-2017.pdf), notes that these coefficients are measures of central tendency (the mean over many test subjects) and thus do not reflect a range of decision-making behaviors. Moreover, one must question their applicability in contexts outside Tversky and Kahneman’s 1992 experiment (in which graduate students were presented prospects with given monetary outcomes and numerical probabilities). The author has explored alternate CPT formulations in the literature that are based on experiments with different populations (including convicted criminals, health-care purchasers, and volunteers subjected to electric shocks) to ensure that the conclusions in this paper are not inconsistent with them. Nonetheless, it is well to adopt the note of caution expressed in Peter J. Phillips and Gabriela Pohl, “Prospect Theory and Terrorist Choice,” *Journal of Applied Economics*, Vol. 18, No. 1 (2014), 139-160, <https://www.tandfonline.com/doi/pdf/10.1016/S1514-0326%2814%2960006-4>, at pp. 146-7: “if [CPT] and its dominant models are to be used to analyse terrorist behaviour, it is an important task for future research to determine the values of these parameters within each terrorism context.” The same can be said with respect to smuggling.

<sup>73</sup> Che and Benson, “Drug Trafficking Wars,” 19.

<sup>74</sup> The demand elasticity for illicit drugs is estimated at  $-0.5$  (ONDCP, *Drug Availability Estimates...*, p. 96).

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