MEASURING BORDER SECURITY FOR RESOURCE ALLOCATION

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ABSTRACT

Nations must secure their borders against unwanted flows of many kinds: drugs; terrorists; counterfeit proprietary goods; and undocumented persons. Effective management of border security requires effective measurement of the impact of alternative policies on those flows. Yet there are no ways to measure any particular inflow, in a given week, month or year. Some indirect indicators are believed to rise and fall with each of these in-flows, but they do not provide an accurate measure of the total flow. We show that they may be combined to estimate the fractional change in each kind of flow. This information, combined with cost information, supports "greedy" resource allocation to counter a single type of flow. This method does not find the absolute magnitude of the cross-border flows, nor yield a single indicator of "the security of the border."

Keywords: Decision Making, Resource allocation, Ray-based modeling; Border Security

INTRODUCTION

Every nation is responsible for the security of its own borders. The United States has land and sea borders, presenting considerable challenges with regard to surveillance, detection and interdiction. The Department of Homeland Security has considered forming some "weighted aggregate" estimate of the security of the border. Given the range of stakeholders, the political forces at play, and the underlying measurement uncertainties, it is not surprising that no such measure has emerged. If such a measure were available, the search for better border policies could proceed as a set of designed experiments, analogous to Taguchi designs in industrial engineering [13]. Various incremental policy changes could be tested individually, or in selected combinations, and a mapped response surface will suggest directions for policy change. The process could, as in manufacturing, be iterated indefinitely, to respond to a changing environment and seek continuous improvement.

There are persistent problems in securing the nation's borders against unwanted flows of many kinds: drugs; terrorists; counterfeit proprietary goods; and undocumented persons. Effective management of border security requires effective measurement of the impact of alternative policies on those flows. Despite work in the social sciences, and adaptation of principles from some other domains, there are no agreed-upon ways to measure the amount of any particular inflow, in a given week, month or year. There are indirect indicators that are believed to rise and fall with each of these in-flows, but they do not provide an accurate measure of the total flow. For example, counterfeit purse seizures probably represent some fraction of all counterfeit purses, at least on the average. Thus a 25% increase in detected purses suggests a 25% increase in the (unknown) number of undetected purses. Similar arguments will apply to other inflows.

Multiple indicators may be adduced to estimate the fractional change in each kind of flow, and using techniques such as ray-cluster analysis, proposed here, an aggregate indicator of the underlying unknown flow may be estimated, *up to an unknown scale factor*. When combined with cost information, this is enough to support resource allocation, for countering *any single type of flow*. Extension to multiple flows requires consensus on the relative importance of the several flows and some resolution of the scale problem. The problem of providing a single reportable indicator of "the security of the border" is even more complicated, and a possible "work around" is discussed briefly. A common data store or "OLAP cube" is recommended as a basis for rational discussion of alternative aggregate measures.

With no overall measure available, that the best course of action is to consider the several harmful flows individually, and look for good measures to counter them. The remainder of this note concentrates on the case of a single flow, and proposes a method called here "Principal Ray Analysis" to estimate the fractional change in that flow.

RAY CLUSTERING AND PRINCIPAL RAY ANALYSIS

We suppose that there is a single flow of interest, and that there are four (for simplicity) imperfect indicators of that flow, each of which is approximately proportional to the flow itself.

Ray Cluster Analysis (RCA)

In contrast to usual statistical analyses of principal components, or Factor Analysis, RCA examines the vectors representing the time series of the indicators, by forming the matrix R_{ij} of inner products of the *normalized* vectors, or rays representing the individual time series $u_t^k,\ k=1,\ldots 4$ where k labels the indicator, and t labels the time (see Table 1).

$$R_{ij} = \frac{\sum_t u_t^i u_t^j}{\sqrt{\sum_t u_t^i u_t^i \sum_t u_t^j u_t^j}} \tag{1}$$

Table 1. The Ray similarities of the four candidate indicators, ImIn1-4.

	ImIn1	ImIn 2	ImIn 3	ImIn 4
ImIn1	1.0000	0.996	0.9998	0.9997
ImIn2	0.9996	1.0000	0.9999	0.9999
ImIn3	0.9998	0.9999	1.0000	0.9999
ImIn4	0.9997	0.9999	0.9999	1.0000

We see that all four of these indicators are (artificially, for purposes of presentation) strongly aligned and so we can take all of them together into our estimate an the underlying factor. If they were not, than some kind of (soft) clustering analysis would be required [6]. This would (mathematically) link each of the indicators to at least one unmeasured flow. Expert judgment would be required to associate the corresponding clusters to specific flows.

Principal Ray Analysis (PRA)

The proposed procedure aggregating the indicators is not unrelated to the concept of orthogonal regression, used in econometrics [8]. We seek a single ray that is most nearly proportional to *all* of the vectors representing the several indicator time series. To find this, from each vector one drops a perpendicular to the ray, thus determining the projection, or the proportionality between that specific vector and the underlying ray, and the distance from that ray to the data series. Minimizing the total squared distance, while holding the direction of the ray on the unit sphere, it is straightforward to show that the closest ray, which is itself a time series, is the non-negative eigenvector of the larger (T *by* T, where T is the number of time periods) matrix M_{st}:

$$M_{st} = \sum_k u_s^k u_t^k \ . \tag{2}$$

The notional data in Table 2 are driven by the factor called “true Level.” Factor Analysis flags the changed levels very clearly. This eigenvector time series is shown in the last column of Table 2. The resulting estimator of the proportional reduction of the unseen factor, 67% is (with synthetic data) in excellent agreement with the actual reduction (from 6 to 4).

Table 2. Factor Analysis Contrasted to Principal Ray Analysis (see text)

ImIn-1	ImIn 2	ImIn 3	ImIn 4	Factor Value	True Level	Principal Ray
18.8	25.0	15.3	39.6	0.596	6	0.313
18.9	24.5	15.4	39.3	0.557	6	0.310
18.1	24.8	15.4	39.8	0.583	6	0.312
12.9	16.1	10.2	26.0	-1.687	4	0.206
12.6	16.4	10.3	26.4	-1.637	4	0.208
12.1	16.9	10.1	26.3	-1.644	4	0.208
18.3	24.8	15.4	39.6	0.579	6	0.311
18.5	25.0	15.0	39.6	0.546	6	0.312
19.0	24.7	15.1	39.1	0.524	6	0.310
19.0	24.0	15.0	39.4	0.470	6	0.309
18.2	24.8	15.0	39.4	0.511	6	0.310
19.0	24.9	15.4	39.5	0.602	6	0.313

Note that familiar factor analysis cannot find this proportionality because the quantities of interest here are ratio-type measures [10, 12], while factor analysis is designed for interval-type measures or scales, and loses the concept of a zero or a proportional decrease.

With an adequate collection of imperfect proportional indicators, this process can be used to contrast a few periods during which an alternative policy is implemented. Subject to practical logistical constraints, these “treatment” periods can be alternated with “baseline” periods. This will facilitate detecting and removing any secular trend effects and perhaps some seasonal variations. A simple average over the two classes indicates *relative sizes* of the unmeasured flow. In this synthetic example, the notional indicators are all tightly linked to the underlying flow, and hence to each other. In reality, the relationships are likely to be much noisier, and it will be important to attend to the estimated precision of the estimated fractional change. This can be done analytically, assuming that the errors are distributed normally [4], while, for other posited distributions, the precision can be estimated using Monte Carlo methods [9].

RECOMMENDATIONS AND TRANSITION

The approach presented here works best if there is a common data store to which all the stakeholders can refer. That data store will contain some data generated by, and belonging to, the government. Other relevant data may come from academic or NGO-sponsored research. There will continue to be behind-the-scenes discussion of how accurately any specific indicator (or factor extracted from indicators) tracks the flow of interest. But it may be hoped that the various stakeholders will focus their disagreements openly on the weights to be assigned to factors, and not engage in back stage lobbying to modify the imperfect indicators(raw data) themselves.

We emphasize, with reference to the scales of measurement, that wherever possible the data store itself should contain summable or "extensive" [14] data about decision units. These data (which correspond to ratio scale measurements) are readily usable at many organizational levels, by adding up the data from constituent units. Ratios, and other indicators as needed are to be computed directly from the data, separately at each level. It is important to ensure that the same event or elementary observation is reported only once, and not double-counted in higher-level analyses.

There are organizational and political barriers to assembling a common data store. Ideally, any data to be collected should naturally arise from the day-to-day operations of the agencies combatting the flows. Such "raw" data may create a permanent record of blunders, and innocent clerical mistakes. Agencies may resist creating such a record of ups and inevitable downs. Resistance originates on the front lines, and is reflected at every layer of management.

Middle level managers may be concerned that a permanent record may reveal that they are doing a very good job with the available funds. In the public sector this tends to decrease funding. One study has identified "recognition" as having high motivating potential for managers in the public sector [7]. But if doing the job done well yields a relative reduction in budget a manager may not feel truly recognized. At the highest levels, officials may resist intercomparable accounting because it may hint that they have not recognized achievement within their own ranks, and they often struggle to maintain their shares of limited funds in competition with all other worthy goals. Contributing data to a common store could be mandated, but, such a top down approach may lead to distortions in data entry [15] or uneven compliance. Prospects for a common data store are better if its existence yields *operational* benefits at multiple levels in participating organizations. Agencies do cooperate, at the front-line level, with informal information sharing about trends seen "on the front lines." As a common data store extends this to higher levels, it may gain acceptance among the responsible agencies. Any stakeholder group that agrees about weights can extend the PRA to compare practices that affect different flows. Many practices (such as drones) have impact on multiple flows.

The PRA analysis proposed here is not elementary, but it should not be difficult to code a script yielding the positive eigenvector of an array, e.g., with Google Sheets. Coupled with a cloud-based data store this approach has these benefits:

1. Operational personnel can enter data, or do focused analyses of the data;
2. A data store could very powerful techniques for resource allocation, such as Data Envelopment Analysis (DEA) [1, 11];.
3. Accumulating data support time-dependent extensions of Capture-Recapture methods [2, 3];
4. Partial public availability may support rational discussion of policy alternatives.

To sum up, it appears possible to aggregate and analyze data in order to support improved allocation of resources and public debate, using the methods proposed here.

LIMITATIONS AND DISCUSSION

The analysis presented here has a number of limitations. First, it provides a guide only for incremental changes in policy with regard to a single kind of inflow. The analysis assumes that the path to best policy can be found by local search, with small or "incremental" changes in the way the flow is countered. This will be valid if desired goal, fractional reduction in the flow, is convex across the entire space of policies. That is unlikely to be true. On the other hand, common sense in governance and law enforcement suggests that only incremental changes would be both administratively and politically acceptable. In other words, the kind of incremental search or "greedy algorithm" that is proposed here may be the best that can be done under the "real world" constraints on border policies.

Second, the quantity of interest is a comparison of the impacts of two specific incremental changes, and those impacts are themselves differences. Furthermore, they are differences in underlying ray-factors that are estimated from noisy data. Thus both the systematic and statistical uncertainties of the estimates will accumulate substantially. It may be hoped that systematic errors affect both the baseline and treatment conditions quite similarly, which reduces their impact on the measured change. On the other hand, it may be that the statistical uncertainties in the two or more time periods are uncorrelated, so that the resulting uncertainties combine in a Pythagorean way. There is not room here to present a detailed analysis of these effects, but preliminary estimates suggest that the problem may be quite significant.

Third, the analysis applies only to any *one specific* flow. This limitation springs from the fact that the ray-based method (and, *ipso facto*, any eigenvalue-based analysis) does not determine the absolute scale of the underlying factor. It seems natural that measures of the overall improvement in border security would, at least locally, take a form similar to:

$$-dS = \sum_{f \in \mathbf{F}} w_f dF_f \tag{3}$$

Here $\mathbf{F}$ is the set of all flows of interest, $-dS$ is the *decrease* in security (as flows increase, security decreases), and w_f, dF_f are the weight and the (small) increase in flow of a particular type of contraband indexed by f. Since the method presented here does not measure the absolute change in any flow, it cannot reveal the change in "security overall." There is one possible "finesse" of this situation. It may be possible to move the conversation from "overall impact" to the importance of "fractional change." This measure will not represent overall security in any economic sense. But it reflects the fact that both politically and administratively it is important to attend to all aspects of the problem. Were that not so, efforts would be concentrated solely on the single kind of flow whose harm can be most reduced by available resources. Instead, the idea of balance can be maintained by modeling the local fractional decrease in *security* as a modified product form:

$$-d\ln S = \sum_{f \in \mathbf{F}} \beta_f d\ln F_f = \sum_{f \in \mathbf{F}} \beta_f \frac{dF_f}{F_f} \tag{4}$$

With this change in perspective, the key stakeholders can be asked to specify the relative importance (the β_f) of *fractional* or *percentage* changes in the flows. As a practical matter, the elicitation process should remind stakeholders and subject matter experts that a large fractional change in a small quantity is probably not very important. This will guide elicitation towards each stakeholder's best estimate of both the magnitude of the flow, and the importance of that flow. In effect, the coefficients β_f will represent the product of two factors each of which is difficult to estimate.

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