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Directional Efficiency Of Criminal Justice System: A Study Of 28 Indian States

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Abstract: India is a country that experiences numerous diversities in terms of religion, language, castes, culture and income inequalities. Societies influenced by such diversities face depleting social capital which indicate poor health of the society. Social ailments might cause heightened negative emotions among the people of the society embedded in jealous, greed and aggression, engender delinquency and crime in Society. Deterrence theorists believed that criminal disposition can be inhibited to some degree of policy maker's choice by sufficiently expanding the activity of Criminal Justices System (CJS) often reflected in certainity, severity and celerity.

This study examines the performance of the Criminal Justice System of 28 Indian States that are grouped to form six provinces. The performance is measured by constructing an empirical envelopment frontier which is the surface of a Free Disposable Hull, a Non-Convex Production Possibility Set. To elevate an observed production plan of an inefficient CJS and place it on the empirical envelopment surface a directional distance function is choosen to serve as a projection tool.

Very Low to very high CJS inefficiency is found to hung over Indian States.

I. INTRODUCTION

Crime is an integral part of the Society. The level of crime reflects public ethics, state's economic strength, people's pleasure and communal harmony. Human being is rational, the choice between legitimate and illegitimate activities is made comparing the utilities associated with them (Gary S. Becker, 1968; Issac Ehrlich, 1973). The risk associates with a crime is apprehension and punishment. If outlawed acts are committed the law enforcement agencies swing into action, efforts will be put into, in order to bring the criminal to justice. On a convicted criminal punishment is imposed often proportional to the crime being committed. The state's punishment triggers panic in the people of the society looking for participation in illegal activities causing a deterrence impact. In the modern world punishment is not corporal, the criminal is put in jail and the prison environment is subject to the state's philosophy. The length of prison sentence and recidivism are thought to be related. Many argue that longer prison sentences are more effective in deterring future crimes. Others argue that longer sentences may induce a relationship between the criminal and fellow offenders in prison and there will be increased recidivism. Empirical studies could not establish a definite relationship between recidivism and longer prison sentences. The Criminal Justice System (CJS) is founded on deterrence.

II. CRIME AND DETERRENCE

The classical philosophers such as, Thomas Hobbs (1588-1678), Cesare Beccaria (1738-1794) and Jeremy Bentham (1748-1832), provided the foundation for modern deterrence theory of criminology. Hobbs opinioned punishment imposed for a crime committed should swallow the benefit derived out of it. Beccario was of the openion that "punishments are unjust when their severity exceed what is necessary to achieve deterrence", that is, punishment should be proportional to the crime, severity beyond necessity may possibly increase recidivism. Control of crime is possible by swift and certain punishment. Beccaria viewed prisons should be more human and the law must not distinguish rich from poor.

"Pleasure and pain are the motives of the rational people and that to prevent crime, the pain as an outcome of punishment may outweigh the pleasure attained by commission of crime" (Beccaria).

Bentham, one of the most prominent philosophers of 18th century believed that the object of the law is to enhance happiness and bring down the pain of the people and punishment in excess to essential to deter people from committing crimes is unjustified.

All the classical theorists believed that human beings are rational, who exercise their free will before an activity is pursued, legitimate or illegitimate.

In twentieth century, crime was viewed in analytic perspective, (Gary S. Becker, 1968; Issac Ehrlich, 1973) and criminal activity participation was analyzed in choice theory frame work.

The deterrence theory founded by Hobbs, Beccario and Bentham relies on three components: Certainty, Severity and Celerity (swiftness with which punishment is administered). Certainty refers to the probability of apprehension and conviction. Larger is the conviction probability greater is the deterrence impact on offenders and potential offenders.

III. CRIME – MATHEMATICAL ECONOMIC MODELLING

Ehrlich (1973) hypothesized that definite relationship exists between probability of capture and conviction, expenditure on Criminal Justice System and Crime Rate. Other things being same, an increase of expenditure on law enforcement may enhance the conviction rate. When other things remain to be the same an increase in crime rate may reduce the conviction rate, implying a negative relationship between crime rate and conviction rate, via work load pressure. Several environmental variables may also influence the conviction rate. Ehrlich proposed a production function in which conviction rate is dependent variable, independent variables being expenditure rate on CJS, Crime Rate and other environmental variables.

Becker (1968) believed the existence of a production function which assumes man power (police & judiciary), materials and capital together produce CJS activity. He postulated a production function,

$$A = f(m, r, c)$$

where A is CJS activity that can be numerically measured
m: Man power
r: Material
c: Capital

A cost is associated with this activity, leading to a cost function in crime context. Cost of police activity is expressed as,

C = C(A)

Inspired by Becker's approach Darrough and Haineke (1979) implemented Cost function approach viewing law enforcement agency as a multiproduct firm. Weighted average of all police wages was choosen as input; Burglary, Robbery, Motor vehicle Theft, Total Number of Crimes against Persons and Clearences as outputs. A Cost Function Specification in law enforcement requires input prices and outputs (Drake and Simpler, 2000).

'Severity' refers to the punishment awarded to the offender. It was believed by the classical philosophers that an increased length of punishment may enhance deterrence effect.

Charles Tittle (1969) empirically established that severity of punishment deters crime if certainty of punishment is reasonably guaranteed. It is clear that in the absence of law enforcement severity of the punishment can not deter crime. In his supply of offence function Becker postulated a relationship between number of offences (dependent variable) and punishment per offence and probability of conviction (independent variables)

$$O = (p, f, u)$$

where O is crime rate
p is conviction rate
f is punishment / offence
u is a vector of environment variables.

Ehrlich (1973) argues that conviction rate and severity of punishment may not be exogeneous variables since they are being determined by public demand and funds. If the crime rate is high, public raise their voice for protection. Consequently, more spending on CJS will take place to combat crime. Improvements in CJS include increase of personnel, purchase of specialized equipment, expansion of prisons, establishment of more forensic laboratories, training of the police personnel and so on.

If crime rate in a period t-1 goes high, due to public demand there will be a rise in CJS expenditure and in period t, p and f will increase to bring down the crime rate to tolerable limit. Demand functions for law enforcement activity can be viewed as a function of crime rate and CJS expenditure in the preceding period (Ehrlich, 1973).

'Celerity' refers to the speed with which punishment is administered, which depends on the performance of the judiciary. The ability to quick-dispose the cases by the justice department reveals the swiftness with which punishment is administered to the offender brought to justice.

"Thus, certainity, severity and celerity govern deterrence".

In supply function specification crime rate appears to be output and in production function specification the same variable is viewed as input in leading econometric studies on crime.

IV. EFFICIENCY MEASUREMENT OF CRIMINAL JUSTICE SYSTEM

Efficiency measurement scores require a frontier of the production possibility set built by sample data and a suitable distance function that helps to project an inefficient production plan interior to the production possibility set to land on its surface. The distance covered to reach the frontier provides an efficiency score and the coordinates of the surface point attained by virtue of projection provide targets to the inefficient producer.

THEORITICAL PRODUCTION FRONTIERS

In economic literature Cobb-Douglas (1928) invented a functional form that was later very widely applied in economic theoretical model building and empirical economics. This production frontier admits diminishing returns, positive output elasticities, a shift parameter and unitary elasticity of substitution. It provides a smooth production frontier that can be differentiable, whose input isoquants are convex to the origin.

Empirical economists tried to estimate the Cobb-Douglas production function by means of both linear and non-linear methods of estimation, some with success and some without. The emergence of the elasticity estimates with wrong signs and wrong magnitudes was due to the involvement of efficiency differences among the production plans used to estimate the production frontier. One can arrive at an appropriate fit of the function, if observations are grouped into two sets, one consisting of dominated observations and the other containing mutually undominated observations. If the later set of observations is implemented a good fit of the frontier can be achieved.

The smooth production frontiers which allow input substitution such as the Cobb-Douglas, the Constant Elasticity Of Substitution (Arrow et.al, 1961), the Variable Returns to Scale (Zellner and Revanker, 1969) and the transcendental logarithmic (Jorgensen & Christensen, 1973) production frontiers are viewed as ex ante production functions. Lieontif's (R.G.D.Allen, 1968) fixed coefficient production function that does not allow input substitution is ex post production function.

Stochastic Frontier Approach (SFA) widely used the Cobb-Douglas Production frontier in efficiency estimation. R.W. Shephard (1970) established duality between cost functions and production functions by means of Shephard's duality theorems. Existence of dual cost functions resulted in building methodology to study cost efficiency differences. Cobb-Douglas production frontiers admit self duality, in the sense that if the production function is of Cobb-Douglas type then the dual cost function is also Cobb-Douglas. The frontiers are implemented not only to measure efficiency differences but also to estimate productivity differences among sampled input and output plans. R.M Solow (1957) used a linear homogeneous frontier to estimate technical change differences. It was subsequenently shown that the technical change estimates (under the same conditions imposed by Solow) obtained by the Cobb-Douglas production functions are identical with Solow's estimates.

These smooth production frontiers, in particular the Cobb-Douglas production frontier can be effectively implemented to estimate input shadow prices.

EMPIRICAL PRODUCTION FRONTIERS

Aigner and Chu (1968), Timmer (1971) pursued chance constrained approach to measure productive efficiency differences among the sampled producers. The Cobb-Douglas Production Function is a convex frontier, that was estimated by Timmer by linear programming approach under the assumptions of free disposability and minimum extrapolation. To measure productive and cost efficiency differences among firms combining two inputs in order to produce a single output Farrell (1957) invented a non-parametric approach, that uses radial measure to project inefficient input plan onto the unit output required inputs determined piecewise linear isoquant. The method though very simple at first, was considered to be seminal contribution towards efficiency measurement. He coined the terms technical, allocative and cost efficiencies, and demonstrated that the input cost efficiency can be multiplicatively decomposed into allocative and technical efficiencies. Farrell's distance function is radial, in the sense that all inputs are contracted proportionately to reach the input isoquant. At each point of the radial path input mix remains to be the same, and due to the absence of input substitution the technique remains to be the same and hence the name 'technical efficiency'. That is efficiency is measured holding the technique to remain the same. Farrell later extended efficiency measurement in the direction of output orientation, which requires equiproportionate output expansion by the inefficient producer to reach the output isoquant.

R.W. Shaphard (1970) introduced the concepts of input and output distance functions both are radial in their nature, but inversely related to the Farrell's input and output distance functions. Shephard's distance functions are axiomatic based, satisfy a number of desirable properties. Input distance functions use input isoquants and output distance functions use output transformation curves as frontiers for projections. Shephard related input distance functions with input sets and output distance functions with output sets. The boundary of input set is input isoquant and the boundary of output set is the output transformation curve, the former being convex to the origin and the later concave to the origin. The input sets and output sets are cross sections of production possibility sets. Shephard (1970) also introduced price sets and established duality between input sets and price sets. The celebrated Shephard's duality theorem has become a valuable tool to link input space with input cost space. It also has become an aid to derive dual cost functions for suitably structured production functions.

Shephard defined his input set as the collection of all input vectors capable of producing a given level of output. The isoquant is made up of piecewise linear segments, convex to the origin. These isoquants are constituted by efficient and weak efficient subsets. The radial input contractions ultimately sink with either efficient or weak efficient subsets. Larger is the output rate farther is the input set from the origin. The input sets are bounded below but not above.

Shephard defined output set as the collection of all output vectors which can be produced by a given input vector. Output sets are always bounded above. Larger is the input rate farther is the output transformation curve from the origin. These output transformation curves are piecewise linear constituted by efficient and weak efficient points. The radial projections, resulting in output expansion land on output transformation curves. Shephard's output distance function is inversely related to his input distance function.

Shephard also introduced graph sets which are full production possibility sets whose cross sections are input sets and output sets. Input sets and output sets are dualistically related. The Graph sets satisfy certain structural properties which are consequently inherited by the input and output sets.

Although, Shephard provided sound mathematical background to distance function approach for efficiency measurement, could not provide a means to empirically estimate technical efficiency.

DATA ENVELOPMENT ANALYSIS – EFFICIENCY MEASUREMENT

Charnes, Cooper and Rhodes (CCR, 1978) who provided empirical approach for efficiency measurement entertained a ratio whose numerator is weighted sum of all outputs and the denominator being weighted sun of all inputs, in the scenario of multiple inputs and multiple outputs. It was assumed that all input and output components were positive and all sampled producers employed similar inputs and produced similar outputs. The numerator and denominator were called as virtual output and virtual input respectively. The production unit, called as decision making unit (DMU) for which the ratio is formed is termed as test DMU_{j0}. Such ratios are formed for all other decision making units. Virtual output per unit of virtual input of test DMU_{j0} was maximized forcing such ratios for all DMUs, including that of test DMU_{j0}, not to exceed unity. The optimization is to obtain optimal weights of inputs and outputs. The optimization problem so formulated was a fractional programming problem. However, this can be transformed into an equivalent linear programming problem, applying Charnes-Cooper transformation. The optimal value of the objective function provides input technical efficiency score that lies between zero and one. If DMU_{j0} attains unit score, then it is either extremely or weakly efficient and less than unit score implies that DMU_{j0} technical inefficient. The CCR measure is a radial measure of efficiency and the problem described above is called as the multiplier problem.

The input and output weights can be interpreted as input and output shadow prices respectively. Input orientation is thus implemented in order to obtain input technical efficiency. CCR input technical efficiency has certain limitations such as, it fails to discriminate returns to scale differences among the decision making units, that is it assumes all DMUs are scale efficient, there by enjoy constant returns to scale; the CCR projections may land in weak efficient subset of the production possibility set; since the projections are radial each inefficient DMU_{j0} is paired with a frontier DMU observable or unobservable if it is a linear combination of more than one production plans such that input mix remains to be same for DMU_{j0} and its paired frontier DMU.

The dual of CCR multiplier problem is called as the envelopment problem. The envelopment constraints are mathematical representation of an abstract production possibility set. The CCR production possibility set is based on the axioms: inclusion, free disposability, convexity, (closure under) ray expansion and minimum extrapolation. It is a convex cone. In CCR input oriented DEA we minimize the objective function subject to the envelopment constraints, forcing the input vector of DMU_{j0} radially to land on the frontier of CCR production possibility set. Due to the fundamental theorem of duality at the optimum the objective function of the multiplier problem and the envelopment problem are equal. CCR input distance function is nothing but Farrell's input distance function which inturn is inverse of Shephard's input distance function.

In CCR output orientation virtual input per unit of virtual output of test DMU_{j0} is minimized forcing the ratio of virtual input to virtual output not less than unity for all DMUs including DMU_{j0}. At the optimum the objective function yields output technical efficiency score for DMU_{j0}, and multiplier weights. The output technical efficiency score will always be larger than or equal to one. The CCR output orientation problem is basically a fractional programming problem that can be transformed into a linear programming problem, applying Charnes-Cooper transformation. The dual of CCR output multiplier linear programming problem in CCR output oriented envelopment problem is which maximum radial expansion of outputs is sought such that the envelopment constraints are satisfied. At the optimum the objective functions of the multiplier and envelopment problems are equal.

The CCR input and output distance functions are reciprocally related. If DMU_{j0} is inefficient, the CCR output approach projects its production plan to land in efficient or weak efficient subset of the frontier of the production possibility set, each surface point of the CCR production possibility set is conceived as a linear combination of input and output plans of extremely efficient decision making units. The common weights used to aggregate inputs and outputs of all decision making units are known as the intensity parameters that are constrained to be non-negative. At the optimum intensity parameters of inefficient production plans vanish, and those of extremely efficient decision making units emerge positive. An output efficiency score of unity implies that the decision making unit (DMU_{j0}) is either efficient or weak efficient. To differentiate extremely efficient decision making units from weak efficient, the sum of input and output slacks are multiplied with an Archimedean quantity that is positive but less than every positive value and the expression obtained is subtracted from the objective function of input oriented problem, but added to the objective function of output oriented problem. Under input orientation DMU_{j0} is said to be extremely efficient if and only if the CCR input / output score is one and all slacks vanish at the optimum.

Economic data are often subjected to returns to scale variation. To model returns to scale in production economics the homothetic and homogeneous production functions are often used. In cost functions elasticity of scale represents returns to scale. It is inverse of proportionate rate of change in factor minimal cost in response to proportionate rate of change in output. The CCR-DEA problem fails to differentiate efficiency scores basing on their returns to scale differences.

Banker, Charnes, and Cooper (BCC, 1984) extended the CCR problem to provide input and output technical efficiency scores which exhibit returns to scale variation. The BCC production possibility set is based on the axioms of inclusion, free disposability, convexity and minimum extrapolation. The BCC production possibility set is contained in the CCR production possibility set, due to which the CCR input technical efficiency score falls short of the BCC input technical efficiency score. The CCR output technical efficiency score exceeds the BCC output technical efficiency score. That is CCR orientation requires greater input contraction and greater output expansion, to attain efficiency. The CCR efficiency scores (input/output) can be multiplicatively decomposed into (input/output) pure technical efficiency and (input/output) scale efficiency. The BCC (input/output) efficiency score is termed as pure technical efficiency. The ratio of CCR efficiency score to BCC efficiency score is termed as (input/output) scale efficiency.

In BCC-DEA if input vector and output vector are projected radially onto the frontier, it is likely that returns to scale at these projection points differ.

Farrell's input/output technical efficiency measures are equivalent to CCR input/output technical efficiency measures but not BCC input/output measures. BCC-DEA based projections either fall in efficient or weak efficient subsets of BCC production possibility set. To distinguish efficient DMUs from weak efficient DMUs slacks are augmented to the objective function as is done in the case of CCR problem.

Deprins et.al (1984) introduced a non-convex frontier, union of orthants determined by all the sample production plans. For a specific DMU_{j0}, the orthant determined by its input and output plan is a set constituted by all the input and output vectors dominated by DMU_{j0}.

In terms of BCC-DEA formulation, if the intensity parameters are forced to take two values 0 or 1, then the BCC production possibility set collapses to Free Disposable Hull. The FDH production possibility set is contained in BCC technology set, to attain technical efficiencies, input contractions and output expansions that are smaller than BCC requirements.

But, to find FDH radial input and output efficiency scores, there is no need to solve 0-1 integer linear programming problems. Tulkens (1993) produced closed from solutions to calculate FDH based input and output technical efficiencies

DEA suffers from lack of discriminatory power. When a DEA problem is solved for all decision making units on the basis of one problem for one DMU several DMUs emerge to be extremely efficient. Therefore, it is hard to differentiate these DMUs. This discriminatory power problem is more felt when FDH frontier is used in the place of BCC frontier.

In the presence of limited sample size, if DEA variables are increased, the number of efficient DMUs will increase forcing DEA to loose its discriminatory power. To preserve discriminatory power, if variables are increased then the sample size shall be increased adqequality, therefore, parsimony shall be entertained while DEA input and output variables are selected. Cooper et.al (2007) suggested a relationship between sample size and number of inputs and outputs.

$$n \geq Max\{m+s,\ 3(m \times s)\}$$

where n: number of DMUs
m: number of input variables
s: number of output variables.

Between smooth frontiers and DEA frontiers there is a relationship. DEA frontier is inner approximation of a smooth continuous frontier. In nonparametric approach of efficiency estimation the non-convex monotone hull (FDH) provides closest inner approximation of the true technology (Fare and Li, 1998). The non-convex targets are always shorter than their convex counter parts. If convexity does not hold then convex efficiency estimates suffer from specification error. For choice between convex and non-convex technologies, refer to (Briec et.al 2004).

SUPER EFFICIENCY

To reduce the problem of loss of discriminatory power, super efficiency can be used as a tool. Petersen and Andersen (1996) introduced the concept of super efficiency for efficient decision making units. To measure either input/output super efficiency of an extremely efficient decision making unit, its input and output vectors are deleted from the reference technology, consequently the DEA frontier experiences modification. The input/ output plan of the test DMU_{j_0} is projected onto the modified boundary so that input / output super efficiency is obtained. The output super efficiency score can not exceed unity. Smaller is the output super efficiency score greater is the ability of the efficient DMU_{j_0} to remain efficient under output contraction.

The super efficiency problems framed under CCR DEA formulation are always feasible, except in special cases where the input and output data admit certain patterns of zeroes, (Zhu, 1996). Under BCC formulation not all input/output super efficiency problems are feasible. If input super efficiency problem is infeasible the output super efficiency problem is feasible. On the other hand, if output super efficiency problem is infeasible, then input super efficiency problem is feasible (Seiford & Zhu, 1998).

Super efficiency as mentioned above is useful to rank the efficiency of decision making units. If more than one DMU admits infeasibility, for example, in input orientation, then all DMUs have the ability to remain efficient under input expansion of any extent. In this case loss of discriminatory power of DEA is still felt.

Xue and Harker (2002) segregates super efficient DMUs as super efficient (SE) and strong super efficient. DMU_{j_0} is said to be simply super efficient, if for atleast one output component the convex combination of all such components of all extremely efficient production plans other than DMU_{j_0} is strictly less than the corresponding output component of DMU_{j_0}. An extremely efficient DMU_{j_0} is said to be strongly super efficient if r^{th} component of each of the efficient DMU (other than DMU_{j_0}) is strictly less than the corresponding output component of DMU_{j_0} and this should happen for atleast one r. Thus, if a DMU_{j_0} is strongly super efficient, then it is simply super efficient. If a DMU_{j_0} is super efficient, then it is strongly efficient, If SSE, SE and E stand for the sets of strongly Super Efficient, Super efficient and strongly efficient DMUs then, following Xue and Harker (2002), we have,

$$SSE \subseteq SE \subseteq E$$

NON-RADIAL EFFICIENCY

Among non-radial distance functions the directional distance functions are very widely used. Chambers et.al (1996) introduced these distance functions, which is a wide class of distance functions. It can be formulated in terms of CCR/BCC constraints. With suitable modifications of the directions the CCR/BCC radial distance functions can be obtained as special cases of directional distance functions. The directional choice may be either exogeeous or endogeneous. The exogeneous directions are pursued by the policy marker and ex-ante producer. The ecogeneous directions may be either data driven (Dario and Simar, 2014) or chosen by the plant manger or the ex post producer. Fare et.al (2013) show that with suitable modifications the directional DEA problem can be equivalent to Tone's slack based efficiency measure. Similar to CCR/BCC models, the directional distance functions can be used to project inefficient production plans onto the FDH frontier. The directional distance function is non-negative irrespective of the direction choosen for input contraction and output expansion. It is homogeneous of degree minus 0ne (-1) in directional vectors' components. In directional distance frame work a specific DMU_{j_0} is said to be efficient if and only if the value attained by it is 'zero' and all slacks vanish at the optimum. Larger is DDF value greater inefficient is the test DMU_{j_0}. Though DDF value is finite, it has no theoretical upper bound specified. However, by suitable choice of the directional vectors, it can be forced to lie between zero and one. In that case zero refers to efficiency and one refers to extreme inefficiency. Zieschang (1984) introduced a hybrid distance function whose path is partly radial and partly non-radal. Since the radial distance functions project certain production plans to land in weak efficient subset, Zieschang limited the radial path to cover certain distance, and from that point Russell (Fare et.al, 2002) non-radial distance function was used to set the residual path to reach efficient subset of the production possibility set. The reason to choose non-radial distance function is that non-radial distance function based projection always leads to the efficient subset of the production possibility set.

Fare et.al (2002) introduced a distance function whose path of projection is non-linear, which is nothing but a rectangular hyperbola. The efficiency measure is called Hyperbolic Graph efficiency for which input is reduced at the rate λ and output expanded at the rate of λ^{-1}, where λ lies between zero and one. The hyperbolic graph efficiency problem is non-linear programming problem. With suitable modifications of the intensity parameters the constraints can be expressed similar to CCR constraints and the problem can be solved as CCR linear programming problem. If the convexity constraint is imposed manipulations of intensity parameters to transform the constraints into linear form is not possible. One can apply, in this case, Taylor's series expansion to attain linearity of the DEA constraints. Johanson and Meginnis (2008) show that the hyperbolic graph based DEA linear programming problems on variable returns to scale frame work do not suffer from the problem of infeasibility, while super efficiency problems are evaluated.

ENVIRONMENTAL EFFICIENCY

In many situations industries/firms produce desirable outputs and non-desirable outputs such as pollutants. Since the undesirable outputs can not be costlessly disposed off, in their case the assumption of free disposability is with drawn. The relevant constraints are expressed as equalities instead of inequalities, since inequalities allow both inputs and outputs freely disposed off. If control of an undesirable output is possible one can attempt maximum control by solving pure ecological efficiency problem in the presence of no free disposability. Konstantineos, Triantis and Paul Otis (2004) postulated environment efficiency measurement problems as CCR/BCC multiplier problems.

Banker and Moorey (1984) segregate inputs into endogeneous and exogeneous and the later can not be controlled by the plant manager or ex post producer. The exogenous inputs are assumed to satisfy free disposability. If environmental influence is confounded in the BCC efficiency measure, Banker and Moorey efficiency score provides a score that is free from environmental effects, consequently yields pure technical efficiency. Therefore, the approach of Banker and Moorey breaks the BCC technical efficiency score into the product of pure technical and environmental efficiency.

TRANSLATION INVARIANCE

An ideal property of any metric is that it should be free from units of measurement. The CCR/BCC efficiency measures are free from units of measurements, whether they are based on convex or non-convex production possibility sets.

The CCR measure is conditioned on positivity of input and output components. Ali and Seiford (1990) introduced translation invariance, which is a desirable property to be satisfied by DEA models. They prove affine transformations of input and output data do not alter the efficient frontier and the DMU that is efficient prior to data transformation remains efficient to posterior to data transformation. The BCC and the directional distance function based DEA models are translation invariant. However, the inefficiency scores alter after data transformation. An advantage with translation invariance is any DEA problem that satisfies this properly can effectively deal with zeros and negative values found in input and output data. Ali and Seiford (1999) show that the additive model (Cooper et.al, 2007) satisfies the property of translation invariant. Tone (2001) demonstrated his slack based efficiency measure too was translation invariant.

CLASSIFICATION STABILITY

Under input contraction and / or output expansion an efficient decision making unit always remains to be efficient. Holding output vector constant, under input expansion an extremely efficient decision making unit turns out to be input technical efficient beyond a threashold point. For input perturbations falling within this bound the test DMU_{j_0} that is efficient preserves efficiency classification.

Seiford and Zhu (1998, 1999) formulated DEA-linear programming problems to identify input and output efficiency stability regions. For an efficient DMU_{j_0}, if input super efficiency problems is infeasible, then DMU_{j_0} remains efficient under input expansion of any extent. If output super efficiency problem is inefficient, then DMU_{j_0} remains efficient under output contraction of any extent.

V. DEA BASED CRIME STUDIES

DEA requires a model expressed in terms of inputs and outputs. But, modelling police is not straight forward since police perform a wide spectrum of activities. We assume all police activities are summarized in conviction rate. In DEA studies number of arrests or clearance rates of crime was used as police output. But, conviction rate reflects the quality of police output and; the depth of police investigation and the success of the police in getting the offender convicted.

Darke and Simpler (2002) in a DEA study chose percentage of time officers spent on patrolling beat, violent crime clearance rate, burglary clear up rate, success rate in answering 999 call, percentage of cases officers arrived at a scene with in a specified response time, as police outputs.

Drake and Simpler (2000) considered total crime clearance rate, total number of traffic offences cleared, and total number of breath analyzing tests as police outputs.

Nyhan and Martin (1999) performed DEA analysis choosing number of unified crime report clearances and response time to call out as police outputs.

Carrington et.al (1997) in their DEA study considered kilometers travelled by police cars, responceses to the offences recorded, number of summons served and number of motor car accidents attended as police outputs.

In a DEA study of police efficiency Thanassoulis (1995) had chosen, Violent Crime clearance rate, Burglary clear up rate other Crime Clear up rate as DEA outputs.

None of these studies considered judiciary output among DEA outputs.

Several DEA explorers used cost efficiency approach to study the police performance (Nyhan and Martin, 1999; Drake and Simpler, 2000, 2000a 2000b, 2000c). Production efficiency approach was followed by Thanassoulis (1995) and Carrington et.al (1997). DEA inputs in Thanassoulis study were number of violent crimes, number of burglaries, number of other crimes, DEA inputs of later authors were number of police officers, number of civilian employees and number of police cars.

VI. PRESENT STUDY

This study aimed at measuring efficiency scores of 28 Indian states. For this, one needs a frontier and a suitable distance function needed to project inefficient production plan to land on the frontier. The frontier adopted is the envelopment surface of free disposable Hull (FDH). FDH is founded on the axioms of inclusion, free disposability and minimum extrapolations. The surface of FDH provides a non-convex frontier. The distance function chosen for projection is the directional distance function whose scores typically depend upon the direction of the projection. The observed input and output direction is chosen as the direction of projection. Directional distance function allows for simultaneous input contraction and output expansion. Directional efficiency scores are constructed for the criminal justice system of each Indian state. The efficient targets that can be constructed for these states implementing directional efficiency scores are shorter than the convex targets

- ✓ Input Target = Observed Crime Rate- Directional Efficiency Score X Observed Crime Rate
- ✓ Police Output Target= Conviction Rate+ Directional Efficiency Score X Conviction Rate
- ✓ Judiciary Output Target= Criminal Cases Disposal rate+ Directional Efficiency Score X Criminal Cases Disposal Rate.

VII. DATA

The data are secondary, collected from the published source, "Crime in India, 2013", Published by Govt of Indian the Variables of the study are,

- ✓ Crime rate(DEA input)
- ✓ Conviction Rate (DEA police output)
- ✓ The rate which cases were disposed off by Criminal Courts (Judiciary output).

VIII. THE PRODUCTION FUNCTION

This study chooses "Crime Rate" as input, which is equal to number of crimes for one lakh population; "Conviction Rate" as police output and the rate at which cases disposed off by the criminal courts" as judiciary output.

IX. NON-CONVEX FRONTIERS – FREE DISPOSABLE FULL (FDH)

Free Disposable Hull that provides non-convex frontier for efficiency measurement, is built on the axioms of inclusion, free disposability and minimum extrapolation. Each extremely efficient production plan determines an orthant, that can be expressed as below:

$$F_k(x_k, y_k) = \{(x, y) : x \geq x_k, y \leq y_k\}$$

where (x_k, y_k) is an extremely efficient input and output vector. The union of all these orthants determine the free disposable hull.

$$F(x, y) = \bigcup_k F_k(x_k, y_k)$$

Under BCC frame work, FDH input technical efficiency problem can be expressed as linear programming problem, whose intensity parameters are bivalent.

$$\lambda_{j_0}^{FDH} = Min\ \lambda$$

such that $\sum_{j=1}^{n} \lambda_j x_{ij} \leq \lambda x_{ij_0},\ i \in M$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{rj_0},\ r \in S$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \in \{0,1\}$$

X. FDH – DIRECTIONAL EFFICIENCY

Chambers et.al (1996) introduced directional distance functions to measure efficiency of decision making units. The CCR / BCC formulations seek proportional input reduction / output augmentation to attain input / output technical efficiency. Where as directional distance functions seek additive input reduction and / or additive output expansion, to reach the production frontier, in the direction of input and / or output directional vector,

$$0 \leq \vec{D}\left(x_{j_0}, y_{j_0}; g_x, g_y\right) < \infty$$

where $\vec{D}$ is directional efficiency

$\vec{D}\left(x_{j_0}, y_{j_0}; g_x, g_y\right) = 0$ implies that

DMU_{j_0} is efficient. Otherwise inefficient. Directional efficiency scores are sensitive to the directions along which inputs are contracted and outputs are expanded. If the frontier is free disposable hull based, directional efficiency scores can be obtained by the methods of enumeration using excel.

XI. FREE DISPOSABLE HULL – DIRECTIONAL SUPER EFFICIENCY

One can derive closed form solutions for directional efficiency, the direction being the direction of input and output vector that are being observed. As an integer (0,1) linear programming problem the super efficiency problem may be expressed as,

$$\theta^* = Max\ \theta$$

subject to $\sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{i0} - \theta x_{ij_0},\ i \in M$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{r0} + \theta y_{rj_0},\ r \in S$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \in \{0,1\},\ j \neq j_0$$

Alternatively, this problem can be expressed as,

$$\theta^* = Max\ \theta$$

subject to $\sum_{j \in D_0}^{n} \lambda_j x_{ij} \leq x_{ij_0} - \theta x_{ij_0},\ i \in M$

$$\sum_{j \in D_0}^{n} \lambda_j y_{rj} \geq y_{rj_0} + \theta y_{rj_0},\ r \in S$$

$$\sum_{j \in D_0}^{n} \lambda_j = 1$$

$$\lambda_j \in \{0,1\}$$

where D_0 is the index set of all extremely efficient decision making units.

For $j \in D_0$ we solve,

$$x_{ij} \leq x_{ij_0} - \theta_j x_{ij_0},\ i \in M,\ j \in D_0$$

$$y_{rj} \geq y_{rj_0} + \theta_j y_{rj_0},\ r \in S,\ j \in D_0$$

$$x_{ij} \leq x_{ij_0} - \theta_j x_{ij_0} \Rightarrow \theta_j \leq \frac{x_{ij_0} - x_{ij}}{x_{ij_0}}$$

$$y_{rj} \geq y_{rj_0} + \theta_j y_{rj_0} \Rightarrow \theta_j \leq \frac{y_{rj} - y_{rj_0}}{y_{rj_0}}$$

$$\theta_j^* = \underset{i,r}{Min}\left(\frac{x_{ij_0} - x_{ij}}{x_{ij_0}}, \frac{y_{rj} - y_{rj_0}}{y_{rj_0}}\right)$$

Following Tulken's approach a closed form expression is derived for Directional Efficiency, replacing the directional vectors by the observed input and output vectors of test DMU_{j_0}.

$$\vec{D}\left(x_{j_0}, y_{j_0}; x_{j_0}, y_{j_0}\right)$$

$$= \theta^* = \underset{j \in D_0}{Max}\ \underset{i,r}{Min}\left\{\frac{x_{ij_0} - x_{j_0}}{x_{ij_0}}, \frac{y_{rj} - y_{rj_0}}{y_{rj_0}}\right\}$$

XII. EMPIRICAL IMPLEMENTATION

The directional efficiency scores are calculated for the Criminal Justice System of 28 Indian States. Union territories are excluded from the study. Geographically these states are divided into six provinces. Since the directional vector follows the direction of observed production plan, the efficiency scores are found to lie between zero and one. A zero valued directional efficiency score implies efficiency and a positive score reveals directional inefficiency. The optimization problem seeks simultaneous reduction of inputs and expansion of outputs. Since the optimization problem ignored environmental variables, the input reduction and output expansion are perceived to happen via criminal deterrence.

NORTH EASTERN STATES

S.No	Name of the State	FDH – Directional Efficiency
1	Arunachal Pradesh	0.7033
2	Assam	0.9707
3	Manipur	0.5835

4	Megalaya	0.5656
5	Mizoram	0
6	Nagland	0
7	Sikkim	0
8	Tripura	0.4532
Mean		0.4095

Table 1

Among 28 Indian States, the Criminal Justice Systems (CJS) of only three states are found to be directional distance efficient, which belong to North Eastern India, (Mizoram, Nagaland and Sikkim). The CJS of Assam emerge to be the most directional inefficient due to the prevelence of high crime rate, low conviction rate and low rate at which cases were disposed off by the criminal courts.

For example, the CJS of Manipur should contract its inputs and simultaneously expand its outputs by 41.65 percent in order to reach the FDH frontier, there by attain directional distance efficiency. On the average, the CJS of the North Eastern province needs to contract inputs and expand outputs by 41 percent to experience directional distance efficiency.

NORTH INDIAN STATES

S.No	Name of the State	FDH – Directional Efficiency
1	Punjab	0.5829
2	Haryana	0.616
3	Uttar Pradesh	0.5148
4	Bihar	0.6837
5	Uttarakhund	0.1695
6	Himachal Pradesh	0.7346
7	Jammu and Kashmir	0.7265
8	Rajasthan	0.3424
Mean		0.5463

Table 2

Among the North Indian States the best performer is the CJS of Uttarakhand (0.1695) which is immediately followed by the CJS of Rajasthan (0.3424). Deterrence effect needs to be strengthened more in Jammu and Kasmir, Himachal Pradesh and Bihar than in other states of North Indian province. In this province on the average crime rate contraction and CJS activity expansion should be approximately 55 percent, for optimal environment to prevail.

SOUTH INDIAN STATES

S.No	Name of the State	FDH – Directional Efficiency
1	Andhra Pradesh & Telangana	0.5878
2	Karnataka	0.4638
3	Kerala	0.2190
4	Tamilnadu	0.2216
Mean		0.3731

Table 3

The Andhra Pradesh and Telangana combined, Karnataka, Kerala and Tamilnadu constitute the South Indian Province. The Criminal Justice System of Kerala and Tamilnadu perform better than Andhra Pradesh and Telangana combined and Karnataka. Criminal deterrence promoting CJS activity is more needed to take place in Andhra Pradesh and Telangana, followed by Karnataka. On the average, the province requires crime rate reduction and CJS activity expansion by 37 percent to reach the FDH frontier.

WESTERN INDIAN STATES

S.No	Name of the State	FDH – Directional Efficiency
1	Goa	0.7701
2	Gujarat	0.7968
3	Maharastra	0.7392
Mean		0.7687

Table 4

Goa, Gujarat and Maharastra constitute Western Indian Province. The CJS of the individual states and CJS of the province as a whole experienced very poor FDH directional distance efficiency. The CJS of Gujarat is the most inefficient, needed greater criminal deterrence effect than Goa and Maharastra. On the average the CJS of Western India should reduce crime rate by 77 percent and at the same rate should expand its CJS outputs in order to reach the frontier.

EASTERN INDIAN STATES

S.No	Name of the State	FDH – Directional Efficiency
1	West Bengal	0.7164
2	Jharkhund	0.3788
3	Odisha	0.6951
Mean		0.5968

Table 5

In Eastern Indian Province the CJS of Jharkhund performs better than West Bengal and Odisha. The most directional inefficient of all the three states is West Bengal. To attain FDH Directional efficiency West Bengal should reduce its crime rate and expand CJS activity by 72 percent. The mean crime rate contraction and CJS activity expansion required by the Eastern Indian Province to attain directional efficiency is about 60 percent.

CENTRAL INDIAN STATES

S.No	Name of the State	FDH – Directional Efficiency
1	Madhya Pradesh	0.6519
2	Chattisgarh	0.7686
Mean		0.7103

Table 6

The Central Indian Province is constituted by the States Madhya Pradesh and Chattisgarh. These are two of the top 10 high crime states, occupying second (Madhya Pradesh) and ninth (Chattisgarh) places. The Central Indian province requires to reduce its crime rate and expand CJS activity by 71 percent in order to reach the FDH frontier.

V. CONCLUSIONS

- ✓ The crime supply function reveals that crime in the Indian states is driven more by the environment, than being controlled by the criminal justice system
- ✓ The Indian Criminals Justice System act on criminal who commit crime and on whom deterrence effect has little influence
- ✓ A one input (crime rate) and two Criminal Justice Systems' outputs (conviction rate and rate at which criminal cases are disposed off by criminal courts) based production function is envisaged to apply Data Envelopment Analysis (DEA).
- ✓ Directional distance functions which seek simultaneous crime rate contraction and Criminal Justice System activity expansion are implemented since such an exercise is not possible if CCR/BCC distance functions are implemented.
- ✓ The frontier of the non-convex production possibility set called Free Disposable Hull (FDH) is implemented to evaluate directional distance efficiency scores
- ✓ For these efficiency scores closed from solutions are obtained and numerical scores are attained by enumeration methods, instead of solving linear-zero-one integer programming problems.
- ✓ The Criminal Justice Systems of Mizoram, Nagaland and Sikkim are FDH-Directional Distance Efficient. These states belong to North East Indian province.
- ✓ In North-East Indian Province Assam followed by Arunachal Pradesh are the very poor performes.
- ✓ Among North Indian states Himachal Pradesh followed by Jammu and Kashmir and Bihar were the very poor performers. In these states high crime rates, poor conviction rates and small rates of criminal cases disposal are witnessed. To attain FDH directional efficiency in these states deterrence effect needs to be much more effective than currently witnessed.
- ✓ The best average performer is the South Indian Province. The crime rate reduction needed in this province is about 37 present and by the same percentage the Criminal Justice System should expand its activity in order to attain FDH-Directional Efficiency.
- ✓ Western Indian province on the average performed worse than all other provinces. To attains FDH directional distance efficiency the input contraction and output expansion needed on the average being 76.81 per cent by enhancing sufficiently the deterrence effect.
- ✓ Of the six Indian provinces pervasion of deterrence effect on criminals is found at lowest level in Western Indian Province. On the average this province shall strive very hard since crime rate reduction and CJS activity expansion shall be at an estimated rate of approximately 77 per cent, to reach the frontier purely by strengthening deterrence effect.
- ✓ Among the three states of eastern Indian provinces (West Bengal, Jharkund, Odisha) West Bengal and Odisha experienced very high levels of inefficiency both in controlling crime and promoting CJS activity reflected in poor conviction rate and inability of the criminal courts in disposing criminal cases at desirable rate. This province to enjoy optional environment shall be able to contract its crime rate and expand CJS activity by 60 percent.

Both Madhya Pradesh and Chattisgarh which constitute the Central Indian Province are placed among 10 top high crime states. To attain FDH-directional efficiency this province shall contract crime rate and expand CJS activity by 71% and this should happen through enhancing deference effect.

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