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# Quantifying Interstate Nuclear Capability: Introducing the Generalized Effect Scores Methodology

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# Quantifying Interstate Nuclear Capability: Introducing the Generalized Effect Scores Methodology

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**Abstract**

Nuclear weapons are undoubtedly powerful and their possession increases the damage a nation can potentially inflict upon an adversary. However, unlike conventional power in the international system, the relative power of nuclear weapons is poorly measured. One solution is to quantify nuclear power through exposure - the portion of the urban population in one country threatened by the nuclear arsenal of an opponent. This paper introduces an original dataset of Generalized Effect Scores (GES) as a quantitative, generalizable means of measuring nuclear power by calculating the exposure of target populations defined by population density, to weapons of specific yields, allowing for the calculation of dynamic dyadic nuclear power for individual weapons, specific scenarios, and entire arsenals. This paper describes the approach theoretically, details the process for calculating exposure scores, and applies these to evaluate the balance of nuclear power between India and Pakistan.

# 1 Introduction

Multiple measures of conventional national power have been proposed in international relations scholarship, most notably the Composite Index of National Capabilities Singer (Singer 1988). However, measuring nuclear capability, or 'power' in international relations has proven more difficult. Functionally, this has resulted in the widespread use of binary indicators of possession, or categorical judgements about relative degrees of dyadic capability (Bell and Miller 2015). While authors in arms control and proliferation literature have largely relied on warhead counts, equivalent kiloton yields, or estimates of the total square kilometer detonation coverage to characterize arsenals. However, none of these measures fully evaluates how much can one country impact another, put simply, the value of possessing an arsenal. Warhead counts provide a very rough approximation, but do not factor in the yields of those weapons, and equivalent kiloton calculations only assess the comparative explosive power of arsenals, or weapons, ignoring features of the target, while square kilometer coverage estimates fail to consider features of populations within targeted countries.

As a consequence, none of these approaches directly address the core issue: how many casualties can one country cause in another? As a solution, this paper suggests an alternative measure of nuclear power based on exposure - the portion of a target's population that is vulnerable to nuclear attack - directly defined as the average proportion of casualties within the urban population one country can inflict upon an opponent. Building on this concept, this paper introduces Generalized Effect Scores (GES), based on comparisons of kiloton yields and urban population density as a generalizable method for computing dyadic nuclear exposure and subsequently, a true quantitative comparative measure of nuclear power. Further, GES is highly flexible and can accommodate both uncertainty in the yield and number of weapons in an arsenal, as well as consideration of the potential impact of missile-defense systems, operational restrictions, and reliability of delivery systems. This paper will conceptually define GES, introduce the GES data set, and demonstrate the potential application, and flexibility of GES as a measure of nuclear power in the case of India and Pakistan.

In a recent article published in the *Journal of Conflict Resolution*, Gartzke and Kroenig (2017) surveyed the current state of international studies research on nuclear weapons; highlighting a range of concerns and research opportunities associated with technological change, doctrinal realignment, proliferation, and non-state actors (Gartzke and Kroenig 2017). Notably, they asserted that, ”nuclear weapons are the ultimate measure of national power. As such, they remain important tools for powerful actors interested in international political competition” (Gartzke and Kroenig 2017, p. 1861). Undoubtedly, nuclear weapons are powerful, they have significant destructive potential, and many people are rightly afraid of them. However, this statement highlights an important point. As a measure of national power, either as a means of forcing potential compellence or deterrence, how powerful are nuclear weapons?

Numerous cross-national comparative measures are available to assess relative national power in international relations, including measures of conventional military power, economic power, and even diplomatic, or soft power. However, most quantitative scholarship on deterrence and the effect of nuclear weapons in international relations has followed the pattern established by Huth, identifying states as either nuclear or non-nuclear, or attempted to categorize dyads based on the relative size of their arsenals or perceived capability, resulting in classification of regional versus global nuclear powers and symmetric verses asymmetric relationships (Huth and Russett 1988; Huth, Bennett and Gelpi 1992; Kroenig 2013; Bell and Miller 2015). While useful, these approaches reduce nuclear weapons to a binary, or at best a categorical variable. Consequently, preventing a direct analysis of the power conferred by the weapons themselves or evaluating their individual potential value. Further, these approaches are implicitly based on the assumption that nuclear weapons automatically allow a thusly armed power to devastate an opponent. This approach does little to clarify the power value of nuclear weapons between countries because it does not assess the actual damage those weapons can potentially cause. Simply put, it fails to quantify the relative value of a nuclear arsenal.

One solution to this problem is to define nuclear power as a function of the potential damage that a nuclear arsenal could inflict upon an adversary, specifically, as a function of the percentage of the urban population that is estimated to become casualties if nuclear weapons are employed, meaning, the relative nuclear exposure, of one country to another. The next section will outline the theoretical assumptions and methods underlying this approach, and define GES as an operationalized measure of nuclear power. The remainder of the paper will then provide an overview of the data used to calculate GES and detail the statistical and simulation methods utilized to compile scores, apply GES to evaluate relative nuclear power between India and Pakistan, and finally, discuss the potential applications and extensions of the GES database.

# 2 Theory

The GES approach begins with the assumption that nuclear power in international relations is fundamentally about potential casualties from a nuclear blast, as a proxy measurement for the amount of damage a weapon is able to cause, meaning the immediate effect of a weapon, rather than secondary effects such as acute radiation exposure, fallout, or long-term radioactive contamination. Consequently, the power of an individual nuclear weapon is essentially a function of two separate and independent processes. First, the size of the weapon, the absolute equivalent explosive yield of the device in kilotons or megatons, which defines the radius of the blast effects, and therefore, the area impacted. Second, the number of people within that area, specifically the population density, which fundamentally defines the pool of possible immediate casualties. As a result, the real impact or power of a nuclear weapon, or by extension an entire nuclear arsenal can only be fully measured in dyadic relationships - taking into account both the yield of the weapon and characteristics of the anticipated target.

This means that the only way to fully answer the question, what can one country do to another in a nuclear conflict? Is to match individual weapons to individual targets and estimate total casualties from a given scenario. This exercise is obviously time-consuming, difficult, and inflexible as a general measure of nuclear power. However, as suggested here, this process can be abstracted to a general approach by using the kiloton yield of a given system and the average national urban population density of a target country. Coupled with the use of randomized simulations based on population density, and existing casualty projection models to estimate generalized effect scores (GES); at given yields and potential target densities, both for individual weapon yields, and therefore, for entire nuclear arsenals.

This is consequently a theoretically Conservative estimation approach. The actual casualties over time from a real nuclear detonation would be larger when the resulting fires, acute radiation exposure, thermal effects, and exposure from fallout are considered. Nevertheless, utilizing blast effects, based on estimating the pounds per square inch of force to which people and structures are subjected and subsequent expected casualties, as an immediate estimation of the impact of a nuclear device is well founded in previous academic and defense policy literature (DCPA 1973; Glasstone and Philips 1977; USIM 1986; Boreham et al. 1989; Curling 2016). Further, this basic damage and casualty estimation method is used as the basis for the 'zoned response' approach adopted in more contemporary US civil planning documents, which describes the environment, types of damage, and necessary response in concentric areas around a nuclear detonation (NSS 2010; DHS 2016). While the modern zoned response system eliminates explicit numeric casualty percentages and concentrates on lower yield events and non-state actors, the description of expected structural damage and references to relative casualty levels remain similar to earlier defense planning assessments. A similar blast over-pressure based estimation technique, augmented by thermal and radiation effects, is used as the basis for modeling nuclear casualties by the NATO Defence Threat Reduction Agency (Curling et al. 2011) Therefore, although more sophisticated models can be constructed to factor in both the blast and secondary effects, the proceeding work provides support for the use of a simple blast estimation approach as a base line generalizable estimate of population level nuclear exposure.

The results from this process represents a time invariant and generalizable method for calculating dyadic nuclear power based on the relative ability of an arsenal to impact the urban population of a target. Repeating this process at multiple yields and population densities allows for the creation of a database of generalized nuclear effects, given a specific yield and target population density.

The resulting GES database could then be applied to any set of nuclear weapons, assuming that estimates of their yields are available, and any given national target, assuming that the size of the urban population, and average urban population density is known. Further, this approach is highly flexible easily permitting the incorporation of uncertainty about the number of weapons a country possesses, or their potential yield by modeling GES numbers based on different projections. In addition, the GES approach, allows different scenarios to be modeled, for example, providing GES scores based on the assumption that a country must divide its available weapons between multiple target countries, or GES scores based on the inclusion, or exclusion of specific systems as a result of range constraints, the effects of missile defense systems, or assumptions regarding reliability or operational readiness. An illustrative case for this would be a calculation of expected GES, employing only a country's ballistic missile submarines in a potential conflict.

# 3 Assumptions of GES

The GES approach outlined above makes four key assumptions. The first is that nuclear power is essentially about the immediate impact of an adversary on a target country, meaning the blast damage of a weapon, not potential residual radiation, fallout, or other secondary effects. The second is that urban areas are the productive and organizational centers of nations, and thus, primary targets of nuclear attacks. suggesting that the percentage of urban population that would be lost in a nuclear attack is the key determinant in potential nuclear power, representing the ultimate threat of one country against another. For this reason, counter-force doctrines, or use of nuclear weapons directly targeting an opponent's arsenal, lie outside of the theoretical scope of the GES concept of nuclear power. The third is that casualties are a joint result of yield, expressed as blast effect, and population density, the potential casualties in a target area, meaning that smaller weapons against more densely populated targets, and larger weapons against more sparsely populated targets can have equivalent effects. The fourth and last assumption is that weapons with equal yields, and targets with approximately equal population densities will experience equivalent casualties, regardless of where they are in the world, or the historical time under consideration.

These assumptions can be summarized with the following four essential rules:

1. Nuclear power is about immediate effects, not secondary effects.

2. Urban areas are the primary targets in nuclear attacks.

3. Casualties are fundamentally a function of yield (blast effect), and population density.

4. Weapons with equal yield and targets with approximately equal density will experience equivalent casualties regardless of where they are in the world.

# 4 Data Sources

The data used to compile GES scores were drawn from two primary sources. First, population density data was collected from the Demographia World Urban Areas (DWUA) report (Cox 2019). DWUA provides average population density, in people per square kilometer, for urban areas with more than 500,000 people worldwide, and provides the average urban population density per square kilometer for countries, based on the same urban area definition. This list of urban areas and population density levels per square kilometer was extracted and used to generate the population density levels between 1000 and 15,000 people per square kilometer used in sampling.

Calculated PSI radii in meters were modeled using NukeMap, a web based application designed to estimate nuclear bomb effects (Wellerstein 2019). Using established prompt effects blast models based on calculations of expected blast pressure in pounds per square inch (PSI) at a given distance, drawing on work by (Glasstone and Philips 1977), and various published U.S. Government sources (Wellerstein 2019). When a blast is simulated NukeMap determines the range at which each PSI level would be felt and reports this as a metric radius. A web-scraper was utilized to collect PSI radii between 1 and 13 PSI for detonation yields between 5 kilotons and 20 megatons. Nuclear detonations were modeled as airburst attacks, and the algorithm was allowed to optimize detonation height to maximize the size of the 5psi radius. This option was selected because 5psi is the estimated point at which most commercial buildings, and the majority of residential structures within the effect zone will be destroyed, and more sturdy structures badly damaged (OTA 1979). This implies an optimal trade-off between maximizing damage, and maximizing coverage and is based on the assumption that a country would want to achieve the largest possible area of effect at a blast level sufficient to cause significant casualties. This process produced a data set of effect ranges by PSI level for different yields. Data was then expanded to include .5 PSI intervals, and the radii were interpolated and verified with spot checks against NukeMap results for .5 PSI ranges to produce a full range of effect radii for corresponding yields.

Data for the percentage of population expected to be killed or injured at a given distance from a blast was drawn from evaluation of multiple blast effects and prompt effects models (Glasstone and Philips 1977; DCPA 1973; OTA 1979). Most of these models are derived from work by (Glasstone and Philips 1977) and function by first calculating the free space PSI in concentric rings around a detonation, and then estimating the percentages of people seriously injured, usually defined as requiring some medical treatment, and those killed in percentage ranges. A general assumption in these models is that normal civilian structures will suffer 100 percent casualties when exposed to forces greater than 12 PSI (OTA 1979). Based on data from these sources 13 PSI was adopted as the top of the scale and assumed to generate 98 percent fatalities, and 2 percent injuries. The minimum PSI value under which no significant injuries should be expected is variously reported as low as .8 (Bentley 1983) or as high as 2 PSI (Boreham et al. 1989) depending on different assumptions. While Glasstone and various US government sources assert 25 percent injuries between 1 and 2 PSI (Glasstone and Philips 1977; OTA 1979) and generally report casualties as averages across PSI ranges. Solomon et al. build on this literature to provide the most detailed and continuous estimations of casualties at increasing levels of PSI blast over pressure (Solomon, Marston et al. 1986). Based on these analyses 1.5 PSI was adopted as the lower bound, and their numbers were used as the basis for injury and fatalities shown in Table 1 below.

This table shows an example for a 100 kt detonation, indicating that 98 percent fatalities and 2 percent injuries are expected within 620 meters of the blast origin, and the radius for the 1 PSI level,

**Table 1: Casualty Percentage By PSI Force 100Kt**

| PSI | Fatalities % | Injuries % | Radius Meters |
|---|---|---|---|
| 1 | 0 | 0 | 9180 |
| 1.5 | 0 | 15 | 7550 |
| 2 | 0 | 35 | 5920 |
| 2.5 | 3.5 | 37.5 | 5280 |
| 3 | 7 | 40 | 4640 |
| 3.5 | 11 | 41 | 4165 |
| 4 | 15 | 42 | 3690 |
| 4.5 | 23.5 | 40 | 3475 |
| 5 | 32 | 38 | 3260 |
| 5.5 | 34.5 | 37.5 | 3040 |
| 6 | 37 | 37 | 2820 |
| 6.5 | 42.5 | 36 | 2290 |
| 7 | 48 | 35 | 1760 |
| 7.5 | 51.5 | 33 | 1665 |
| 8 | 55 | 31 | 1570 |
| 8.5 | 56.5 | 30 | 1400 |
| 9 | 58 | 29 | 1230 |
| 9.5 | 60.5 | 27 | 1130 |
| 10 | 63 | 25 | 1030 |
| 10.5 | 64 | 24.5 | 965 |
| 11 | 65 | 24 | 900 |
| 11.5 | 65.5 | 24 | 835 |
| 12 | 66 | 24 | 770 |
| >12 | 98 | 2 | 620 |

at which no casualties are expected is 9,180 meters from blast origin. At intermediate distances within this space, varying levels of fatalities and injuries are expected to occur as shown. These estimates are necessarily generalizations and have some margin of error, because the actual effect and therefore, lethality of a blast depends upon numerous factors. Such as the terrain, the type of construction material, whether a building has been subject to multiple blasts, and even whether people are assumed to be standing, or prone at the time, the shock wave arrives (Boreham et al. 1989). Despite these restrictions, these values are intended to be generally indicative of the level of casualties generated by a blast of a given size.

Finally, this effect radius and casualty percentage data was used as an input to a blast simulation program written for this purpose in Netlogo version 6.1.1 (Wilensky et al. 1999) and randomized simulations were run to generate expected casualties by yield and population density. The modeling process, outputs, and construction of the final GES scores will be presented in the next section.

# 5 Method

Using these data sources, a database of GES scores was created based on selected kiloton yields at intervals between 5kt, and 20,000kt, and urban population densities between 1000 people per square kilometer and 15,000 people per square kilometer, in increments of 1000. See table 2 below, providing example GES scores for an average 11,000 person per square kilometer target at multiple kiloton yields.

The resulting GES database was compiled in two steps. First, simulations of blast effects were run 1000 times for each yield and population density level, and the resulting injury and fatality estimates collected. Second, each 1000 run sample was averaged to create the final calculated GES score, representing the estimated effect of a weapon of a given yield against a target with a specified average urban density.

An example of the blast simulator interface is shown in Figure 1. The simulation takes the average population density per square kilometer, the total size of the simulation space in kilometers,

**Table 2: GES by Kt Yield at 11,000 Per Sqr Km**

| Yield | GES | Yield | GES | Yield | GES |
|---|---|---|---|---|---|
| 5 | 105466 | 150 | 1011851 | 1500 | 4710195 |
| 10 | 169061 | 200 | 1237922 | 2000 | 5724857 |
| 12 | 186337 | 300 | 1607536 | 3000 | 7499093 |
| 15 | 220203 | 400 | 1956520 | 4000 | 9058289 |
| 20 | 266069 | 500 | 2257330 | 5000 | 10523038 |
| 25 | 306815 | 600 | 2575060 | 10000 | 16720276 |
| 30 | 351394 | 700 | 2845575 | 15000 | 21962088 |
| 40 | 425424 | 800 | 3093671 | 20000 | 26547022 |
| 50 | 487836 | 900 | 3354386 | | |
| 100 | 777941 | 1000 | 3616785 | | |

and the size of sub-kilometer divisions in meters, as well as a population variance as a percentage. Based on these inputs, a simulation space is created, defined by the given world size in kilometers, and each square kilometer is assigned a population from a random normal distribution with the mean set at the selected population density and a given density variance. A population density variance of 20 percent was used for these simulations. Each square kilometer is divided into 100-meter blocks, and the total population for that kilometer evenly distributed across the blocks. This means that the total population between square kilometers is allowed to vary significantly, to represent real variation in urban population distributions. However, the average population across all simulated kilometer squares is guaranteed by the normal distribution function, to be approximately the same as the specified density per square kilometer. This can be seen in Figure 1, where lighter kilometer squares have higher population numbers. This was implemented to induce realistic random variation in the target population, while allowing for controlled and generalizable simulations of blast effects.

Once the simulation environment is initialized according to the parameters outlined above a detonation is simulated at the center of the simulation space, and the resulting casualty effects are calculated based on PSI level, effect radius, and casualty percentages as outlined above. This process is performed in a series of iterative rounds, starting with the radius in meters for the highest PSI value for a given yield and working outward. Each PSI level is called, the radius is determined from data, and all 100-meter squares within that radius are selected. The given casualty percentages for this PSI level are then applied to the population in each square, and the total running injury and fatality estimates are recorded. Finally, the square is marked as affected, so that it is not calculated again by a subsequent blast radius, and colored as shown in Figure 1 to denote the PSI radii. This process is repeated, moving outward from the center until all PSI levels have been checked. The final casualty totals are then summed, and the values are recorded. This full process, randomly building the simulation space, calculating a detonation, and recording the results are repeated 1000 times for each yield and population density combination.

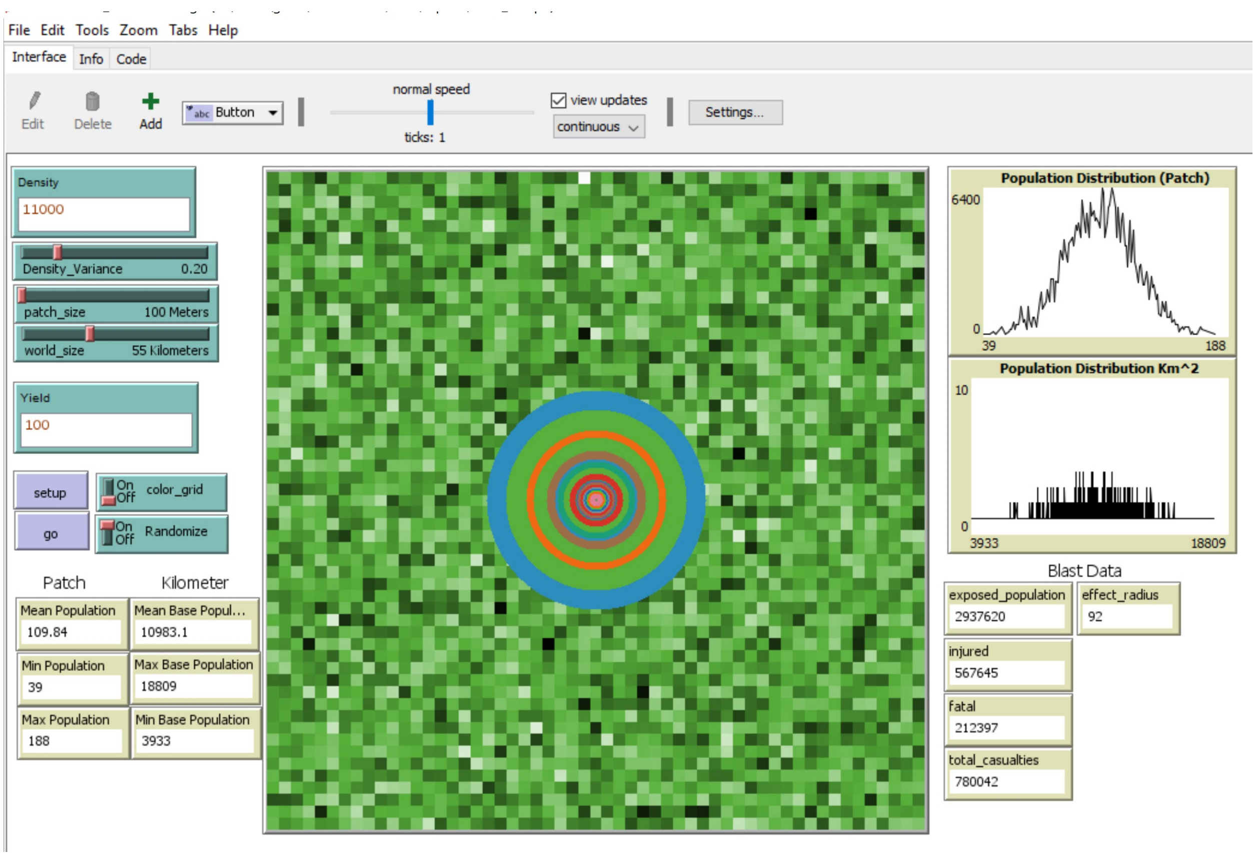


**Figure 1**

Final GES scores are derived from this simulation data by averaging the injuries and fatalities for all 1000 simulations for each yield and density combination. The resulting GES score is the combined total of average fatalities and injuries, based on the assumption that all fatalities, and anyone with a serious enough injury to require medical attention is at least temporarily disabled and represents the immediate estimated effect of a weapon against a population. This highlights an important point. GES scores can be conceptualized in two different ways, depending on what a researcher wishes to measure. Either as a direct indicator of the immediate population impact - the portion of a countries' urban population that will be seriously affected by a nuclear weapon, or working backward to the over pressure based structure damage estimations underlying the casualty model, the population casualty estimates themselves can be considered a proxy for the degree of infrastructure and economic destruction and dislocation caused by an attack. In which case the GES value as a ratio of urban population represents the proportion of developed urban zones, which will be seriously damaged in an attack.

This database of GES scores can be used to evaluate the dyadic nuclear power of a given country against a potential target by finding the average urban population density of the target country and the total urban population of the country. The GES scores for the weapons in the aggressor's arsenal can then be totaled by evaluating the kiloton yield of each weapon against the closest population density level in the data, Resulting in an estimated total number of casualties in the target country for a weapon, or group of weapons. Comparing this estimate to the total urban population of the target country reveals the percentage of the targets urban population which could be impacted, or in other words, how exposed the target is to the potential aggressor.

$$Exposure = \frac{\sum W \times GES_{yd}}{P} \tag{1}$$

This process is illustrated in equation 1 above. The total GES for a weapon system, or an arsenal, shown as exposure is calculated by summing the total number of weapons (w) with a given kiloton yield, times the GES value for that yield (y) at a given density (d) Resulting in a total estimated number of casualties for that group of weapons divided by the total urban population of the target country (p). The next section will demonstrate an application of this concept to the case of India and Pakistan.

# 6 India-Pakistan Case

India and Pakistan have a long history of animosity, including recurrent military clashes with the potential for escalation to war. In fact, the 1999 Kargil War represents the only case of a major war, as defined by the 1000 battle related deaths standard, between two nuclear armed countries since 1945 (Geller 2005). Further, despite the conventional superiority of India in the Kargil conflict it has been argued that Pakistan could initiate the war precisely because both countries were equipped with nuclear weapons and that the risk of nuclear escalation rendered a long conflict "unthinkable" (Paul and Paul 2005, p. 15). However, this assessment is ultimately based on the assumption that possession of nuclear weapons is, in and of itself, a deterrent, without offering a more granular assessment of their relative impact, or power. Put simply, knowing that a country possesses nuclear weapons does not directly infer the potential leverage those weapons might afford.

Given the ongoing potential for renewed hostilities between India and Pakistan, this case represents an ideal application for the GES concept, allowing a true assessment of relative nuclear power between these countries. In conventional terms, India strongly dominates Pakistan. Both in potential military capability, with a CINC score 5.5 times higher than Pakistan (Singer et al, 2012); and economically, with a per capita income that was 1.4 times larger in 2012, and 1.7 times larger today (World Bank Development Indicators, 2018). Yet, despite these differences it is seemingly often assumed, and sometimes explicitly argued that the duel possession of nuclear weapons acts as an automatic equalizing factor (Batcher 2004).

In order to better evaluate this assumption this section presents an assessment of the relative nuclear power of these two countries below. Table 4 demonstrates GES scores for India, against Pakistan, or in other words, India's nuclear power versus Pakistan, Both by weapon system and as a collective arsenal. These estimates were derived using the process for calculating GES outlined above. India has an average urban density of 11,000 people per square kilometer, and a total urban population of 244,040,000 people (Cox 2019). Pakistan has an average urban density of 10,600 people per square kilometer and a total urban population of, 46,200,000 (Cox 2019). Turning to their respective arsenals, the actual size of weapons for the two countries is also similar, ranging between 12 and 60kt (Kristensen and Korda 2018; Kristensen, Norris and Diamond 2018). For this estimation, GES values for the 11,000-person density have been range employed as shown in table 3 above and the expected effect of a 60kt weapon extrapolated from the difference between sampled 50kt and 100kt estimations.

**Table 3: Generalized Effect Score India verses Pakistan**

| System | Number | Range | Yield | Total Kt | Warhead GES | GES | GES% |
|---|---|---|---|---|---|---|---|
| Aircraft | | | | | | | |
| Vajra (Mirage 2000) | 16 | 1850 | 60 | 960 | 546569 | 8745104 | 18.9 |
| Shamsher (Jaguar) | 32 | 1600 | 60 | 1920 | 546569 | 17490208 | 37.8 |
| Land Based Missiles | | | | | | | |
| Agni-III | 8 | 3200 | 40 | 288 | 425911 | 3407288 | 7.3 |
| Agni-II | 8 | 2000 | 40 | 800 | 425911 | 3407288 | 7.3 |
| Agni-I | 20 | 700 | 40 | 320 | 425911 | 8518220 | 18.4 |
| Prithivi-II | 24 | 350 | 12 | 320 | 186568 | 4477632 | 9.6 |
| Sea Based Missiles | | | | | | | |
| K-15 | 12 | 700 | 12 | 144 | 186568 | 2238816 | 4.8 |
| Dhanush | 2 | 40 | 12 | 24 | 186568 | 373136 | 0.8 |
| Pakistani Urban Population | 46200000 | | | 4776 | | **48657692** | **105** |
| Urban Density $Km^2$ | 10600 | | | | | | |

The data in table 3 indicates that India is estimated to be able to cause approximately 48,000,000 casualties in Pakistani urban areas. Accounting for 105 percent of the Pakistani urban population. This capability is roughly equally distributed between air delivered bombs, 56%, and missile-based systems, 48%, suggesting that even if India was unable to use any air delivered systems, due to Pakistani air defenses, it would still be able to impact approximately half of the Pakistani urban population. Additionally, India retains a nominal second strike capability provided by a single operational Arihant-class missile submarine, armed with 12 K-15 missiles, with a capability limited to roughly 5 percent of the Pakistani population, enough to destroy the capital, but otherwise far from an assured second strike deterrent.

**Table 4: Generalized Effect Score Pakistan verses India**

| System | Number | Range | Yield | Total Kt | Warhead GES | GES | GES% |
|---|---|---|---|---|---|---|---|
| Aircraft | | | | | | | |
| Mirage III | 12 | 2100 | 12 | 144 | 186568 | 2238816 | 0.9 |
| F-16 | 24 | 1600 | 12 | 288 | 186568 | 4477632 | 1.8 |
| Land Based Missiles | | | | | | | |
| Shaheen-2 | 12 | 1500 | 40 | 480 | 425911 | 5110932 | 2 |
| Ghauri | 24 | 1250 | 40 | 960 | 425911 | 10221864 | 4.1 |
| Shaheen-1 | 16 | 750 | 12 | 192 | 186568 | 2985088 | 1.2 |
| Babur GLCM | 12 | 350 | 12 | 144 | 186568 | 2238816 | 0.9 |
| Ghazanavi | 16 | 300 | 12 | 192 | 186568 | 2985088 | 1.2 |
| Abdali | 10 | 200 | 12 | 120 | 186568 | 1865680 | 0.7 |
| NASR | 24 | 70 | 12 | 288 | 186568 | 4477632 | 1.8 |
| Indian Urban Population | 244040000 | | | 2808 | | **36601548** | **15** |
| Urban Density $Km^2$ | 11000 | | | | | | |

Table 4, above estimates GES for Pakistan against India. Indicating that Pakistan is estimated to be able to cause approximately 36,000,000 casualties within Indian urban areas, accounting for 15 percent of the Indian urban population. Although Pakistan also maintains a large number of air delivered weapons, they make up a smaller proportion of the overall GES, accounting for roughly one-fifth of the total Pakistani capability. Without air delivered systems Pakistan is still capable of jeopardizing approximately 12 percent of the Indian urban population, suggesting that proportionally, more of Pakistan's nuclear power is allocated in missile systems and could therefore be more likely to reach their targets, given the current distribution of capabilities.

At first glance, comparing only the raw GES numbers these arsenals seem to be quite balanced. Both are capable of inflicting tens of millions of casualties, despite Pakistan possessing roughly half as many total kilotons as India. However, when the GES scores are considered as a percentage of the respective target's urban populations, this apparent similarity vanishes. Based on these estimations in a best-case scenario, using all weapons India can totally destroy all urban zones of Pakistan. Even assuming a limitation to missile-based systems the Indian GES% still accounts for approximately half of the Pakistani urban population. In contrast, under ideal circumstances, Pakistan is capable of jeopardizing 15 percent of the Indian urban population, a significant blow, but far short of the damage they are likely to suffer in return under any circumstances.

Collectively, these numbers suggest that India dominates Pakistan both in nuclear, and conventional terms. In fact, a comparison of the relative GES percentage shows that India's nuclear power, as measured here by exposure, is roughly seven times larger than Pakistan - A strikingly similar result to the comparison of relative military power based on CINC scores discussed earlier.

Although a nuclear conflict would clearly be costly for India, and perhaps more costly than Indian leaders would willingly tolerate, it would be essentially annihilatory for Pakistan. As a result, this analysis suggests that the strategic relationship between India and Pakistan is not balanced by nuclear weapons. Instead, the same asymmetry seen in conventional terms is reproduced in this measure of nuclear power. Under all circumstances, India is more powerful than Pakistan despite both countries possessing nuclear weapons.

# 7 Uses and Extensions

The approach to quantifying nuclear power suggested here offers several potentially valuable contributions. First, it is comparable, generalizable, and atemporal. Given that the yield of a weapon, the average population density, and total urban population of the target country are known, or estimable, GES scores can be applied to calculate nuclear exposure both for historical as well as contemporary or future interactions. GES, therefore, like other measures of international power has the ability to evaluate changes in power over time. In addition, GES has potential applicability to evaluating incentives for proliferation, nuclear arms races, and the expansion of nuclear arsenals. For example, by calculating the amount of expansion required to achieve a specific degree of nuclear power in a dyadic relationship - the change in GES required to match a larger opponent.

Or the level of nuclear capability required to make proliferation viable for a near nuclear state.

Furthermore, GES can be adapted to consider uncertainty. For example, if the size or capability of an emerging nuclear arsenal is unclear, but the potential range of capability is estimable, GES can be adjusted to provide multiple estimates based on varying assumptions. In addition, GES can implement scenario analysis and consider adjusted scores based on assumptions about delivery system reliability, the impact of missile-defense systems, and strategic or doctrinal limitations, which might restrict the available portion of an arsenal. In addition, GES could be used in conjunction with other measures of international power to create joint measures that incorporate conventional, as well as nuclear capabilities. Finally, GES is not theoretically limited to duel nuclear dyads. Exposure could be calculated against any country, not just to evaluate cases of nuclear parity or asymmetry as shown here.

# 8 Limitations

GES is intended as a general measure of nuclear power. It is not intended to be as accurate as calculating individual attack portfolios on a case by case basis, and this paper does not argue that it should fully replace such analysis. GES instead offers flexibility and generalizability as a measure of nuclear power, similar to the use of CINC scores, or GDP as a general estimate of national power. Further, GES is based on a relatively simple, and conservative blast casualty model. Although it could certainly be extended to attempt to factor in estimable acute radiation and conflagration effects, it is intended for use by international relations, proliferation, and conflict scholars as a measure of immediate nuclear capability. It is not intended to compete with fully specified nuclear physics models in estimating the effects of individual weapons or blasts in specific locations.

In addition, GES is fundamentally based on the assumption that potential nuclear power in international relations is related to the ability to endanger the population of an adversary or estimate the amount of infrastructure damage that can be caused. It does not attempt to measure counter force capability. Additionally, because it is based on the assumption of air-burst detonations, it is not directly applicable to non-state actors, who are unlikely to be able to place a nuclear device above a target, although theoretically, the underlying approach used to calculate GES could be replicated for low yield ground level detonations. Finally, the actual range of weapons in an arsenal, or the ability to deliver them to a target must be considered by the researcher and cumulative GES values should be adjusted accordingly. In the case of weapon systems with limited range, this can be done by considering the proportion of target urban areas within range and proportionally adjusting the final total GES values accordingly. In the case of reliability, countermeasures, or the effect of operational restrictions these should be factored in by removing an appropriate number of systems from the final calculation, in which case the cumulative adjusted GES represents a form of scenario analysis.

# 9 Conclusion

This paper has introduced the GES estimation technique and data set as a new measure of comparative national nuclear power, based on the proportion of the urban population of an opponent exposed to potential nuclear attack. Arguing that this proportion, the estimated pool of urban casualties as a percentage of overall urban population represents the quantifiable power of a nuclear weapon. As such, this value is estimable, as shown here, and can be used as a measure of nuclear power. Either to demonstrate the relative nuclear exposure of adversaries in a dyad, as illustrated with the case of India and Pakistan, demonstrating that India significantly dominates Pakistan, or as a measure of exposure for non-nuclear armed states threatened by nuclear armed opponents. Further, GES scores provide a direct, and continuous measure of nuclear power, which potentially allows a true quantitative estimation of the impact of nuclear weapons on international relations. Allowing a more sophisticated analysis of power relationships, and a better quantitative test of deterrence theories and the impact of nuclear weapons in international interactions. The ultimate aim of this paper, and the associated GES data set is to provide these estimations, in order to allow researchers to easily evaluate these questions for any combination of countries and arsenals.

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