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Use of the disaster deficit index in the evaluation of the fiscal impact of future earthquakes

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ABSTRACT

The Disaster Deficit Index (DDI) measures disaster country risk from a macroeconomic and financial perspective, according to possible future catastrophic events. The DDI captures the relationship between the demand for contingent resources to cover the maximum probable losses and the public sector's economic resilience; that is, the availability of internal and external funds for restoring affected inventories. For calculating potential losses, the model follows the insurance industry in establishing a probable loss, based on the critical impacts during a given period of exposure, and for the economic resilience the model computes the country's financial ability to cope with the situation taking into account: the insurance and reinsurance payments; the reserve funds for disasters; the funds that may be received as aid and donations; the possible value of new taxes; the margin for budgetary reallocations; the feasible value of external credit; and the internal credit the country may obtain. Access to these resources has limitations and costs that must be taken into account as feasible values according to the macroeconomic and financial conditions. This paper presents the model of DDI and the results for fourteen countries of the Americas to design appropriate risk evaluation tools to guide the governmental decision making.

KEYWORDS: Disaster deficit, contingent liabilities, fiscal sustainability, seismic vulnerability.

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1. INTRODUCTION

Disaster risk management requires measuring risk to take into account not only the expected physical damage, victims and economic equivalent loss, but also social, organizational and institutional factors. The difficulty in achieving effective disaster risk management has been, in part, the result of the lack of a comprehensive conceptual framework of disaster risk to facilitate a multidisciplinary evaluation and intervention. Most existing indices and evaluation techniques do not adequately express risk and are not based on a holistic approach that invites intervention. The various planning agencies dealing with the economy, the environment, housing, infrastructure, agriculture, or health, to mention but a few relevant areas, must be made aware of the risks that each sector faces. In addition, the concerns of different levels of government should be addressed in a meaningful way. For example, risk at the local level is very different from risk at the national level. Risk is most detailed at a micro-social or territorial scale. As we work at more macro scales, details are lost. However, decision making and information needs at each level are different, as are the social actors and stakeholders. If risk is not presented and explained in a way that attracts stakeholders' attention, it will not be possible to make progress in reducing the impact of disasters. This means that appropriate evaluation tools are necessary to make it easy to understand the problem and guide the decision-making process. It is fundamentally important to understand how vulnerability is generated, how it increases and how it builds up. Performance benchmarks are also needed to facilitate decision makers' access to relevant information as well as the identification and proposal of effective policies and actions.

A system of indicators is proposed to meet this need and to enable the depiction of disaster risk at the national level, allowing the identification of key issues by economic and social category. It also makes possible the creation of national risk management performance benchmarks in order to establish performance targets for improving management effectiveness. Four components or composite indicators were designed to represent the main elements of vulnerability and show each country's progress in managing risk. This paper presents one of them related to the macroeconomic potential impact: the *Disaster Deficit Index* (DDI). These indicators were developed by the Institute of Environmental Studies (IDEA in Spanish) of the National University of Colombia, in Manizales, for the Inter-American Development Bank, in the framework of its Program of Indicators for Disaster Risk and Risk Management in the Americas. Program reports, technical details and the application results for the countries in the Americas can be consulted at the following web page: http://idea.unalmzl.edu.co (Cardona 2005, IDEA 2005, Carreño et al. 2007a/b).

2. DISASTER DEFICIT INDEX

The DDI measures country risk from a macroeconomic and financial perspective according to possible catastrophic events. It requires the estimation of critical impacts during a given period of exposure, as well as the country's financial ability to cope with the situation. This index measures the economic loss that a particular country could suffer when a catastrophic event takes place, and the implications in terms of resources needed to address the situation. Construction of the DDI requires undertaking a forecast based on historical and scientific evidence, as well as measuring the value of infrastructure and other goods and services that are likely to be affected. The DDI captures the relationship between the demand for contingent resources to cover the losses, L_R^P, caused by the Maximum Considered Event (MCE),[1] and the public sector's economic resilience, R_E^P, that is, the availability of internal and external funds for restoring affected inventories[2]. Thus, DDI is calculated using Eqn 2.1, as follows:

$$DDI = \frac{L_R^P}{R_E^P} \qquad (2.1)$$

where

$$L_R^P = \varphi L_R \qquad (2.2)$$

L_R^P represents the maximum direct economic impact in probabilistic terms on public and private stocks that are governments' responsibility. The value of public sector capital inventory losses is a fraction φ of the loss of all affected goods, L_R, which is associated with an MCE of intensity I_R, and whose annual exceedance rate (or return period, R) is defined in the same way for all countries (i.e. return periods of 50, 100 and 500 years, whose probability during any 10 years exposure period is 18 percent, 10 percent and 2 percent, respectively). This total loss L_R, can be estimated as follows:

$$L_R = E\ V(I_R C_S)\ K \qquad (2.3)$$

where, E is the economic value of all the property exposed; $V(\,)$ is the *vulnerability function*; I_R is the intensity associated to the selected return period; C_S is a coefficient that corrects intensities to account for local site effects; and K is a factor that corrects for uncertainty in the vulnerability function.

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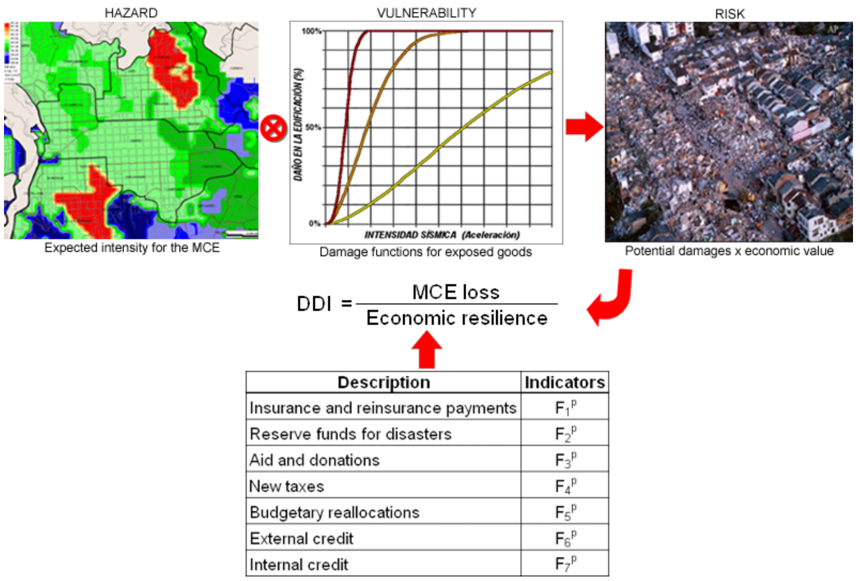
[1] This model follows the insurance industry in establishing a reference point for calculating potential losses (ASTM, 1999) or the common concept of Probable Maximum Loss, PML, broadly used for risk evaluation of portfolios of buildings (Ordaz and Santa-Cruz, 2003).

[2] A similar approach estimating the resource gap has been proposed by Freeman et al. (2002b). In this report they say that being able to quickly access sufficient funds for reconstruction after a disaster is critical to a country's ability to recover with minimal long-term consequences.

Economic resilience, R_E^P (the denominator of the index), is defined in the following equation:

$$R_E{}^P = \sum_{i=1}^{n} F_i{}^P \qquad (2.4)$$

where F_i^P represents the possible internal and external resources that were available to the government, in its role as a promoter of recovery and as owner of affected goods, when the evaluation was undertaken. Access to these resources has limitations and costs that must be taken into account as feasible values according to the macroeconomic and financial conditions of the country. Figure 1 shows a diagram illustrating the way to obtain the DDI.



$$\text{DDI} = \frac{\text{MCE loss}}{\text{Economic resilience}}$$

Description	Indicators
Insurance and reinsurance payments	$F_1{}^P$
Reserve funds for disasters	$F_2{}^P$
Aid and donations	$F_3{}^P$
New taxes	$F_4{}^P$
Budgetary reallocations	$F_5{}^P$
External credit	$F_6{}^P$
Internal credit	$F_7{}^P$

Figure 1 Diagram for DDI calculation

A DDI greater than 1.0 reflects the country's inability to cope with extreme disasters even by going into as much debt as possible. The greater the DDI, the greater the gap between losses and the country's ability to face them. If constrictions for additional debt exist, this situation implies the impossibility to recover. To help place the DDI in context, we have developed a complementary indicator, DDI', to illustrate the portion of a country's annual Capital Expenditure, $E_C{}^P$, that corresponds to the expected annual loss, Ly^P, or the pure risk premium. That is, DDI' shows the percentage of the annual investment budget that would be needed to pay for future disasters.

$$DDI' = \frac{L_y^{\,P}}{E_C^{\,P}} \qquad (2.5)$$

The pure premium value is equivalent to the annual average investment or saving that a country would have to make in order to approximately cover losses associated with major future disasters. Other DDI' was also estimated with respect to the amount of sustainable resources due to inter-temporal surplus, S_i^P. That is to say, the percentage the technical premium of potential savings at present values represents as expressed:

$$DDI' = \frac{L_y^{\,P}}{S_I^{\,P}} \qquad (2.6)$$

The sustainable amount of resources due to inter-temporal surplus, S_i^P, is the saving which the government can employ, calculated over a ten year period, in order to best attend the impacts of disasters (IDEA 2005). What we need to know is if the government, from an orthodox perspective, complies with its inter-temporal budgetary restriction. That is to say, if the flows of expenditures and incomes guarantee –in present value terms– that current and future primary surpluses allow a canceling of the present stock of debt. In other words, financial discipline requires that government action be limited and that the financial capacity to deal with disasters must comply with the inter-temporal restriction of public finances. In the case that annual losses exceed the amount of resources available in the surplus it is predicted that over time there will be a debt due to disasters that inevitably increase the overall debt levels. That is to say, the country does not have sufficient resources to attend future disasters. In the case that restrictions to additional indebtedness should exist, this situation would signify that recovery is impossible. In general, if inter-temporal surplus is negative, premium payment would increase the existent deficit.

3. ESTIMATING PROBABLE LOSSES

The computation of losses during future natural hazard events (index numerator) is always a very complex problem. Due to the uncertainties of this process, losses must be regarded as random variables, which can only be known in a probabilistic sense, i.e. through their probability distributions. Consequently, this approach has been adopted in this model (Ordaz and Santa-Cruz, 2003). Given existing knowledge, it is clearly theoretically impossible to predict the times of occurrence and magnitudes of all future natural hazard events. In view of the uncertain nature of the processes involved, our second best choice is to estimate the probability distribution of the times of occurrence and impacts of all future disasters. In general, however, this estimation is also a titanic task. A convenient way of describing the required probability distributions (those of the occurrence times and the sizes of the physical impact) is the use of the exceedance rate curve of the physical losses (Loss Exceedance Curve). This curve relates the value of the loss with the annual frequency with which this loss value is exceeded; the inverse of the exceedance rate is the return period. The PML curve is equivalent to the LEC. An example of this risk metric is depicted in the Figure 2.

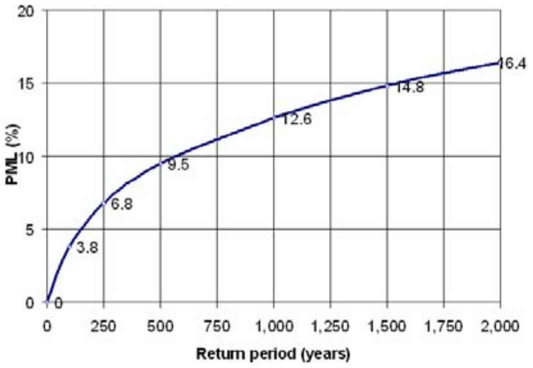


Figure 2 Example of a PML curve with the results for several return periods

There is a large body of work in the past decades on earthquake loss estimation and more recently with GIS; e.g. the ATC-13 (Applied Technology Council, 1985) and the HAZUS (FEMA, 1999) that have been considered outstanding methods. See also Coburn and Spence (1992) and the EERI Earthquake Spectra Loss Estimation Theme Issue (1997). See details of risk model in “Probabilistic seismic risk assessment for comprehensive risk management: Modeling for innovative risk transfer and loss financing mechanisms” by Cardona et al. in these proceedings.

3.1. Hazard

In this context, *intensity* is defined as a local measure of the disturbance produced by a natural event in those physical characteristics of the environment relevant to the phenomenon under study. For all types of hazards, it is almost impossible to describe the intensity with a single parameter. For instance, when dealing with earthquake hazards, the peak ground acceleration gives some general information about the size of the ground motion, but does not give indications about its frequency content. This is crucial for an accurate estimation of structural response. In view of this, it is understood that a single-parameter description of intensity will always be incomplete. However, a multi-variable description of intensity is far too complex for our goals (actually, very few, if any risk studies undertaken in the past, have considered multi-variable descriptions of intensity). We propose to use a single measure of intensity for each type of hazard that correlates well with damage and for which hazard measures are relatively easy to obtain. It should be noted that since we are mainly interested in disasters that have an economic impact at the national level, we have restricted ourselves to those hazards that produce large, immediate economic losses, like earthquakes or hurricanes. Other hazards, like landslides, are extremely important at local level, and historically have produced many victims. However, their economic impact has been very limited. Slow on-set disasters, like drought, are also very important, but their economic impacts are deferred over time. As these do not have immediate effects, they are beyond the scope of the proposed estimation model.

In many cases, hazard estimations are obtained from regional studies, or by assuming average environmental conditions. For example, seismic hazard maps are usually produced assuming average firm soil conditions, i.e. assuming that there are no significant amplifications of seismic intensity due to soft soils. Also, wind velocity maps are generally produced assuming average exposure conditions, that is, velocities are not obtained for sites on hills, but for reference sites. However, for each type of hazard, particular environmental characteristics may exist in the cities under study that cause intensities to be larger or smaller than the intensities in the neighborhood. In other words, environmental characteristics may exist that differ from those corresponding to the standard characteristics used in hazard evaluation. These characteristics are known as *local site conditions*, and they give rise to *local site effects*. In the framework of the present project, the local site effects in all cities and for all types of hazards are impossible to take into account in any accurate manner. Our first rough approach would be to simply ignore the site effects. However, there are cases in which the local site effects cannot be disregarded. Since by definition these site effects are local, it would be impossible for us to give general rules for values of C_S for all cities and types of hazard. In our view, appropriate values would have to be assigned by the local experts who participate in the loss estimations for different countries. Once an appropriate intensity is chosen for each type of phenomenon, a probabilistic hazard description must be given. Usually, the hazard is expressed in terms of the exceedance rates of intensity values. It must be noted that, for our purposes, we require *local* indications of hazard, that is, exceedance rates of intensity at the points or cities of interest (one of our assumptions is that all property in a city is concentrated in a point or in a geographical area of limited size). In principle, a hazard curve must be constructed for every type of hazard and every city under study. However, recalling Eqn 2.3, it is needed just a few points of this curve, namely those intensities associated to the selected return periods. In the case of seismic hazard the intensity is calculated taking into account the sum of effects of all seismic sources located in a certain influence area. Hazard expressed in terms of exceedance rates of the peak accelerations for firm soil, a, is calculated through the following expression (Esteva 1970):

$$\nu(a)=\sum_{i=1}^{i=N}\int_{M_0}^{M_u}-\frac{\partial\lambda}{\partial M}\Pr(A>a\,|\,M,R_i)dM \qquad (3.1)$$

where the sum includes all the seismic sources, N, and $Pr(A>a|M,R_i)$ is the probability of the intensity exceeding a certain value, given the earthquake's magnitude, M, and the distance between the ith source and the site, R_i. The $\lambda(M)$ function represents the activity rates of the seismic sources. The integration is done from M_0 to $M_{u,}$, which indicates that the contribution of all magnitudes is taken into account for each seismic source. It is important to note that the previous equation would be exact if the seismic sources were points. In reality, they are volumes, therefore the epicenters cannot only occur in the centers of the sources, but can also occur, with equal probability, in any point inside the corresponding volume. Supposing that the intensity variable has a lognormal distribution given the magnitude and distance, the probability $Pr(A>a|M, R_i)$ is calculated in the following way:

$$\Pr(A>a\,|\,M,R)=\Phi\left[\frac{1}{\sigma_{\ln a}}\ln\frac{MED(A\,|\,M,R)}{a}\right] \qquad (3.2)$$

being $\Phi(\cdot)$ the standard normal distribution, $MED(A|M, R_i)$ the median value of the intensity variable (given by the corresponding attenuation law) and σ_{Lna} the standard deviation of the natural logarithm of a. In Eqn 3.1and Eqn 3.2 both the attenuation law and its uncertainty are included. The seismic hazard is expressed in terms of the exceedance rates of given values of seismic intensity. The seismic intensity, a, refers to the pseudo acceleration response spectra ordinates for a 5% of critical camping for a given structural period, T. Once the attenuation laws are calculated for different structural periods, it is possible to determine uniform hazard spectra for a specific site, based on the calculated intensity value (acceleration) for a fixed return period.

3.2. Vulnerability

As indicated in Eqn 2.3, $V(I)$ is the vulnerability function, which relates the intensity of the event, I, with the expected fraction of the value that is lost if an event of such intensity takes place.

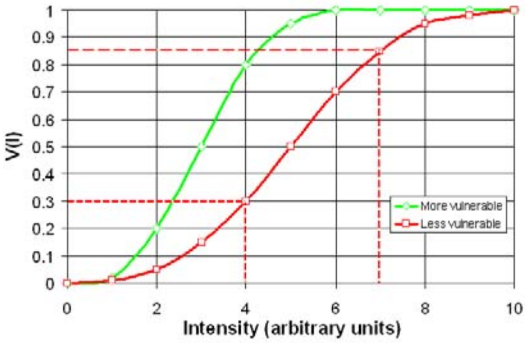


Figure 3. Representation of vulnerability functions

Vulnerability functions usually have shapes like that shown in Figure 3. A building is said to be *more vulnerable* than another if greater damage is expected in the former than in the latter given similar hazard intensities. Vulnerability functions are highly hazard-specific. In other words, in the same city, buildings and infrastructure might be very vulnerable to a certain hazard and much less vulnerable to another. As defined, vulnerability functions might change depending on technological, educational, cultural and social factors. For instance, for the same seismic intensity, buildings in a city might be more vulnerable than buildings in another city due to higher dissemination of construction technology or application of seismic-resistant design in the latter. In rigor, vulnerability functions should be expressed in the following way:

$$V(I) = V(I;\phi) \tag{3.3}$$

where ϕ is a set of parameters that will be denoted as vulnerability factors. In fact, it is through these factors that the effects of prevention can be appreciated, and their economic impact can be assessed. Consider, for instance, that the vulnerability curves correspond to earthquake hazard. Here it is conceivable that the application of seismic-resistant design in a city (a change in one of the vulnerability factors) could move the vulnerability function from the “more vulnerable” to the “less vulnerable” case of Figure 3. Usually, the costs of development, implementation and enforcement of seismic regulations would be much less than the amount saved by reducing the vulnerability, so improving the design practices would be a sound decision even from the economic point of view. A discussion about probabilistic benefit-cost ratio is presented in the paper "Probabilistic seismic risk assessment for comprehensive risk management: modeling for innovative risk transfer and loss financing mechanisms" of Cardona et al. of these proceedings.

As it may be noted in the preceding paragraphs, we always refer to $V(I;\phi)$ as being related to the *expected* damage, that is, to the expected value (in the probabilistic sense) of the damage. Due to the uncertainties involved, it is impossible to deterministically predict the damage resulting from an event with a given intensity. Thus, we try to predict its expected damage with $V(I;\phi)$, keeping in mind that there are uncertainties that cannot be neglected. There are, of course, rigorous probabilistic ways to account for this uncertainty. One way of solving this problem is to find a factor, that we call K (Eqn 2.3), which relates the loss estimator that would be obtained accounting for the uncertainty with the loss estimators obtained disregarding this uncertainty. Factor K depends on several things: the uncertainty in the vulnerability relation, the shape of the intensity exceedance rate curve, and the return period. We have found that, under reasonable hypotheses, a factor of K=1.2~1.3 is reasonable for our goals.[3] The vulnerability functions can be expressed analytically using:

$$V(I) = 1 - \exp\left\{\ln 0.5\left(\frac{I}{\gamma}\right)^{\alpha}\right\} \tag{3.4}$$

where α and γ are parameters that define the shape of the function. Table 3.1 shows some values of α and γ for some building constructions (Ordaz and Santa-Cruz, 2003).

Table 3.1 Parameters for some vulnerability functions

Construction class	α	γ
Non reinforced masonry	5.0	0.25
Confined masonry	5.5	0.50
Reinforced concrete frames	3.0	0.40

So far, our analysis has been restricted to estimate losses in cities or regions of limited geographical size. The key to the definition of “limited geographical size” is our hypothesis that everything within the city is affected simultaneously by the event under study. In reality, damage during disasters varies, sometimes widely, even within a city, so our hypothesis hardly, if ever, holds. But, this assumption has to be made for the sake of simplicity. However, for extensive regions, comprising several cities, perhaps hundreds of kilometers apart, it would be extremely risky to assume that everything is affected simultaneously. In view of this, we have to derive ways to combine the computed loss estimators for each city in order to obtain a reasonable combined estimator for the whole country. We shall call these

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[3] Note that if a constant factor K=1.2 is used for all countries, cities and types of hazard then it becomes irrelevant for comparison purposes. However, we prefer to deal with K explicitly for two reasons. The first is of symbolic nature: it helps to keep in mind that our estimation process is uncertain and that we must account for uncertainty in a formal way. The second reason is that, as defined, our loss estimators have a clear meaning: they are economic losses, measured in monetary units. Thus, their scale is relevant.

rules the *aggregation rules*. IDEA (2005) presents details about the mathematical relations between the exceedance rates and other interesting and useful measures of risk; the rigorous probabilistic ways to account for the vulnerability uncertainty and the derivation on the loss-aggregation rules proposed.

4. RESOURCES POTENTIALLY AVAILABLE

Economic resilience (the denominator of the index, see Eqn. 2.4) represents internal and external resources that were available to the government when the evaluation was undertaken. Seven constraints are explicitly taken into consideration in this study: *Insurance and reinsurance payments* (F_1^P) that the country would approximately receive for goods and infrastructure insured by government; *Disaster reserve funds* (F_2^P) that the country has available during the evaluation year; public, private, national or international *aid and donations* (F_3^P); *New taxes* (F_4^P) that the country could collect in case of disasters; *Budgetary reallocations* (F_5^P) which usually corresponds to the margin of discretional expenses available to the government; *External credit* (F_6^P) that the country could obtain from multilateral organisms and in the capital market; and *Internal credit* (F_7^P) the country may obtain from commercial banks as well as the central bank. IDEA (2005) presents a method for estimating taxes on financial transactions. In addition, it presents a model for calculating the external financial situation of a country and the access to internal credit taking into account the associated uncertainties. It is important to indicate that this estimation is proposed considering restrictions or feasible values and without considering possible associated costs of access to some of these funds and opportunity costs which could be important. Figures 4 and 5 present the application results for some countries in the Americas (Cardona 2005; Carreño et al. 2005, IDEA 2005).

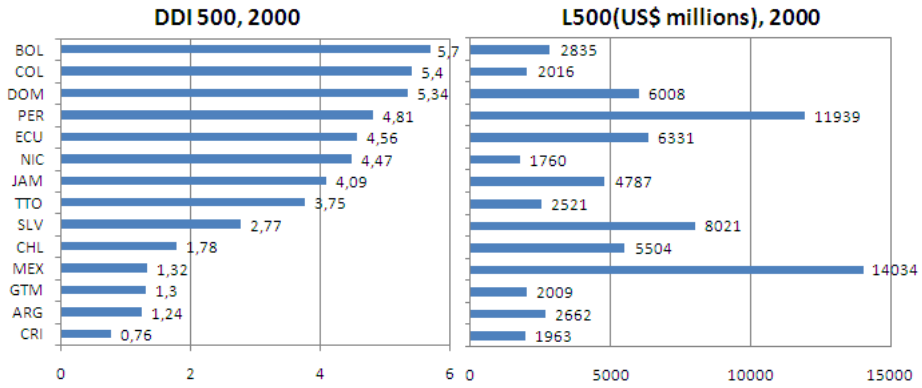

Figure 4 DDI and Probable Maximum Loss in 500 Years

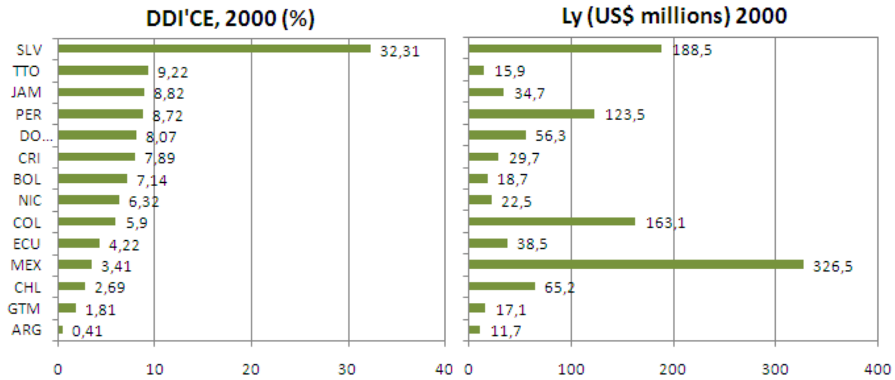

Figure 5 DDI$_{CE}$' and Annual Probable Loss

5. CONCLUSIONS

These indicators provide a simple way of measuring a country's fiscal exposure and potential deficit (or contingency liabilities) in case of an extreme disaster. They allow national decision makers to measure the budgetary implications of such an event and highlight the importance of including this type of information in financial and budgetary processes. These results substantiate the need to identify and propose effective policies and actions such as, for example, using insurance and reinsurance (transfer mechanisms) to protect government resources or establishing reserves based on adequate loss estimation criteria. Other such actions include contracting contingency credits and, in particular, the need to invest in structural retrofitting and rehabilitation, and nonstructural prevention and mitigation, to reduce potential damage and losses as well as the potential economic impact of disasters. The approach proposed here is fundamentally a probabilistic risk model similar to those used for loss transfer and retention aims. Due to this, it is substantially different to that used by UNDP (2004), to estimate the Disaster Risk Index, DRI, or at *Hot Spots* project of World Bank (2004), and to those applied in the majority of the models proposed for estimating the impact of disasters on economic growth. The present approach was chosen given that serious theoretical controversies still exist in terms of whether disasters cause a significant impact on economic development. According to the results obtained by Albala-Bertrand (1993, 2002) disasters usually affect the less productive capital and unskilled labor. Therefore, while leading to profound social consequences, they have little effect on the macro economy of a country. Similar models have been formulated by IIASA and Freeman et al. (2002a/b). Benson et al. (2003) and

ECLAC (2003) amongst others, argue that in the long run such impacts may be important for certain economies. IDEA (2005) presents an analytical approach about growth and disasters. It concludes that disasters may reduce the savings level in society and thus the amount of capital and product per person in the stationary state, i.e. recurrent and random disasters affect per capita income and growth rates in the long term.

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