Analysis of Vulnerability Index Across Countries Using Multiple Linear Regression [1]

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ABSTRACT. This research aims to build a model that explains a country's vulnerability to extreme natural events using indicators related to disaster preparedness and management. The indicators used in this study are the following: exposure index, world giving index, education index, health expenditure, forest area, female population, gross domestic product per capita, population ages 15-64, institutions index, infrastructure index, goods market efficiency index, technological readiness index, and innovation index. Vulnerability was regressed using the aforementioned indicators. The final regression model has the remaining independent variables: world giving index, education index, gross domestic product per capita, infrastructure index, and population ages 15-64. The results of this study can be used as a guide to explain the dynamics of and to reduce a country's vulnerability to extreme natural events.

I. INTRODUCTION

For many years, human activity has been pushing the planet into its limit. The unceasing needs and desires of human beings to discover and convert natural resources into useful and fancy things continue to drive the massive production of harmful gases into the atmosphere. These harmful gases in turn, led to global warming or the sweeping rise in temperature. In effect, global warming triggered imbalance in the earth's typical processes, thereby causing drastic changes to climate. With the global effect of climate change, all countries around the world are now exposed to the impending threat of natural events.

Attempts to restore the planet into its healthy state through environment-friendly activities, policies, and advocacies like tree-planting and plastic use reduction have been promoted by concerned individuals and organizations worldwide. However, it cannot be denied that there is also an urgent need for the society to learn to safeguard itself from the perils associated to natural events. Exposure alone does not determine whether natural events would turn into disasters. Instead, it is accompanied by vulnerability, which is within the societal sphere. If the society knows how to deal with extreme natural events, then their impact will be more tolerable for the resulting damages could be made less likely. Between exposure and vulnerability, the society should invest in knowing how to minimize the latter, knowing that it is not beyond control.

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Various researches have been made to identify the societal indicators that make up a country's vulnerability to extreme natural events. Knowing these indicators will aid government leaders, policy-makers, and other concerned individuals and organizations to strengthen the country's disaster preparedness and management program; and to make its coping and adaptive mechanisms more intact.

This study initially targets to explore more indicators that are considered to contribute to a country's vulnerability to extreme natural events. Then, it aims to present a linear regression model that explains how the significant indicators quantitatively relate to vulnerability. Lastly, it intends to determine the accuracy of the identified model.

II. RELATED LITERATURE

Vulnerability is defined by the World Health Organization (WHO, 2002) as the degree to which an individual or a group of individuals is incapable of anticipating, coping with, and recovering from the impacts of disasters. In line with this, the Development Helps Alliance in its Work Risk Report 2017 identified three components that make up vulnerability: susceptibility, lack of coping capacity, and lack of adaptive capacity. Susceptibility refers to the probability of the society to suffer damage due to a natural event. Lack of coping capacity is the inability to reduce the negative impact of a natural event to the society. Lack of adaptive capacity pertains to absence of long-term actions aimed to transform a society given its degree of exposure to natural events. The three components all rely on the readiness of the society when it is faced with extreme natural events. Explained in the succeeding paragraphs are the societal indicators that contribute to a country's vulnerability to extreme natural events.

Poverty is pointed out as a major contributor to vulnerability, as it may result in malnutrition, homelessness, poor housing and destitution (WHO, 2002). In 2004, Philip and Rayhan analysed the interrelationship between vulnerability and poverty. Their study confirmed that poverty is generally associated with deprivation of health. They further added that it is also associated with education, food, knowledge, influence on one's environment, and other things that differentiate living from merely surviving. They concluded that the poor are more susceptible to health hazards, economic decline, man-made violence, and natural disasters. Later on, De Silva and Kawasaki (2018) investigated the relationship among poverty, disaster risk, and vulnerability of households and communities in Sri Lanka. Results showed that households heavily depending on natural resources for livelihood and that those with low income suffer greater financial losses from floods and droughts compared to households with high income. Wu, et al. (2018) observed that at the national level and especially for the developing countries, economic vulnerability to calamities decreases as income increases. For a change, they studied the case of China at the subnational scale and showed that economic development is correlated with the significant decrease in human mortalities due to natural disasters. They also demonstrated that economic development level is correlated with human and economic vulnerability to climate-related disasters, which is decreased with the increase of per capita income.

Bastaminia, Rezaei, and Saraei (2017) focused on studying how to increase resilience rather than how to reduce vulnerability. They used regression and were able to identify that an increase in the household head's education level, length of stay in current neighbourhood, and household income could result in an increase in social and economic resilience of the household studied. Also, their study showed that social capital is an important determinant of resilience.

The Development Helps Alliance in its World Risk Report 2017 stressed the importance of local and international relief operations as coping mechanisms. It explained how international relief is more in demand in the presence of "weak statehood" or lack of good governance. The demand for other nations to respond to the emergency needs of the country damaged by natural disasters is affected by the ability of the national government and of the civil society to adapt to the country's degree of exposure to natural events. It is important for the national government to initiate the refinement of disaster prevention and relief in different ways such as effective urban planning and well-disseminated evacuation system. These refinements are eventually projected to improve the responsiveness of the civil society when help is needed by fellow citizens.

When a disaster strikes, children, pregnant women, the elderly, malnourished and ill people, and persons with disabilities (PWDs) are more vulnerable (World Health Organization (WHO), 2002). These are the part of the population that needs special protection and extra assistance in the face of extreme natural events (World Risk Report, 2017). In the Philippines for instance, women, children, senior citizens, and PWDs, collectively determined as the most vulnerable sector, are mandated to be involved in risk assessment and planning in Local Government Units (LGUs). Also, guidelines for the establishment of Disaster Risk and Reduction Management Offices and Committees specifically require an efficient mechanism for immediate provision of food, shelter, and medicine for women and children. The need for a special place for breastfeeding mothers is also considered (Republic Act of 10121)**.**

The role of forests and coastal ecosystems as natural shields and protective barriers that reduce the impact of natural disasters was also emphasized (World Risk Report, 2017). The Food and Agriculture Organization (FAO) Regional Office for Asia and the Pacific considered forestry as one of the many contributors to disaster risk management. Coastal forests may help reduce the impact of tsunamis by reducing the wave's energy. On the other hand, they may serve as liability for very large tsunamis as the strength of the said extreme natural event may carry over the forest debris further inland.

Another critical factor considered to contribute to vulnerability is the presence of fragile infrastructures, the slow progress in information technologies, and the delayed advancement in transport monitoring systems (World Risk Report, 2017). Montz and Tobin (2004) recognized the role of technological innovations such as Geographic Information Systems (GIS), remote sensing, satellite imagery, and by advances in data collection and dissemination in understanding the dynamics of natural hazards and in minimizing damage that may be caused by natural events. They also stressed the need to invest in technologies within political, social, and economic systems in order to control vulnerability.

Summing up, it can be observed that vulnerability to extreme natural events is at large, affected by indicators that may be controlled or improved: factors associated to poverty such as amount of income, quality of health, and level of education; government ability; size of vulnerable sector; condition of natural protective barriers; advancement in technological innovations; etc. In fact, the Development Helps Alliance puts vulnerability under the sphere of societal control, emphasizing that damage due to extreme natural events is not determined solely by exposure, but more predominantly by the ability of the society to harness together its awareness and capability for disaster preparedness and management (World Risk Report, 2017).

III. METHODOLOGICAL SKETCH

Data for this research were obtained from different sources. Vulnerability index and exposure index were adapted from the World Risk Report 2017. World giving index came from the CAF World Giving Index 2017 report. Institutions, infrastructure, goods market efficiency, technological readiness, and innovation index were sourced from the Global Competitiveness

Report 2017-2018. Countries with no data for a specific variable were deleted through SAS software. 110 countries were involved in this study.

a. DEFINITION OF VARIABLES

Dependent variable

Vulnerability index (%) (VUL) – Vulnerability is calculated as the average of susceptibility (S), lack of coping capacity (loCC), and lack of adaptive capacity (loAC).

$$VUL = \frac{1}{3}(S + loCC + loAC)$$

Susceptibility is a function of public infrastructure which is explained by the share of population without access to improved sanitation (A) and share of the population without access to an improved water source (B), nutrition which is explained by the share of undernourished population (C), poverty and dependencies which is explained by the dependency ratio (D) and extreme poverty population living with USD 1.25 per day or less (E), and economic capacity and income distribution which is explained by gross domestic product per capita (F) and GINI index (G). Susceptibility is also supposedly a function of housing conditions but is not included due to unavailability of sufficient global data.

$$S = \frac{2}{7}\left[\frac{1}{2}(A + B)\right] + \frac{1}{7}C + \frac{2}{7}\left[\frac{1}{2}(D + E)\right] + \frac{2}{7}\left[\frac{1}{2}(F + G)\right]$$

Lack of coping capacities is a function of government and authorities which is explained by Corruption Perception Index (A) and good governance (B), medical services which is explained by number of physicians per 10 000 inhabitants (C) and number of hospital beds per 10 000 inhabitants (D), and material coverage which is entirely explained by insurance coverage (E). Disaster preparedness and early warning as well as social networks also contribute to lack of adaptive capacities. However, they are not included due to unavailability of sufficient global data.

$$loCC = 1 - \left\{0.45\left[\frac{1}{2}(A + B)\right] + 0.45\left[\frac{1}{2}(C + D)\right] + 0.1E\right\}$$

Lack of adaptive capacities is a function of education and research which is explained by adult literacy rate (A) and combined gross school enrolment (B), gender equity which is explained by gender parity in education (C) and share of female representatives in the parliament (D), environmental status which is explained by water resources (E), biodiversity and habitat protection (F), forest management (G), and agricultural management (H), and investment which is explained by public health expenditure (I), life expectancy at birth (J), and private health expenditure (K). Adaptation strategies factor contributes to lack of coping capacities. However, it is not included due to unavailability of sufficient global data

$$loAC = 1 - \frac{1}{4}\left[\frac{1}{2}(A+B) + \frac{1}{2}(C+D) + \frac{1}{4}(E+F+G+H) + \frac{1}{3}(I+J+K)\right]$$

Independent variables

Education index (score from 0 to 1) (EDUC) – Education index is the part of human development index that accounts for Expected (EYSI) and Mean Years of Schooling Index (MYSI). The Expected Years of Schooling (EYS) counts the number of years that a child is expected to attend school or university from primary up to tertiary education. The Mean Years of Schooling (MYS) is a calculation of the average number of years of education undergone by population of age 25 years and above; the average is based on the theoretical duration of the specified educational attainment level. In the formula, 15 is the projected maximum MYS for 2025. 18 is the maximum EYS and also a sufficient number of years to accomplish master's degree in most countries, not considering possible changes in prevailing patterns of age-specific enrolment rates.

$$EDUC = \frac{EYSI + MYSI}{2}$$

where $EYSI = EYS \div 18$

$$MYSI = MYS \div 15$$

In this study, education index is used to quantify literacy which is related to the ability of an individual to read and understand precautionary measures in times of natural events. This is also used to describe the impact of a society that has experts honed enough to lead and be able to raise their country's awareness. Education is expected to be inversely related to vulnerability.

Exposure index (%) (EXPOSURE) – It is a function of the number of people that are exposed to the following natural hazards: earthquakes (A), cyclones (B), and flooding (C) and of the number of people that are threatened by drought (D) or sea level rise (E), and the total population in the country (P). In the formula, 0.5 is used to counter the possibility of overestimating the number of people threatened by drought and sea level rise.

$$EXPOSURE = \frac{A + B + C + 0.5(D+E)}{P}$$

In this study, exposure is used to replace the continental location indicator. Instead of using the continental location to tell something about the proneness of a country to natural events, exposure is used. It is possible that the higher the exposure, the higher the vulnerability will be. However, if a country has superior disaster preparedness and management, coping, and adaptive mechanism, the negative consequences of exposure may be alleviated.

Female population (% of total population) (FEMALE) **–** This tells the percentage of the population that is female. Women are assumed to be more vulnerable to natural events than men. In general, women are physically weaker than men, making them more incapable to protect themselves in times of natural events.

$$\frac{Female\ population}{Total\ population} \times 100$$

In this study, it is expected that higher population of women makes the country more vulnerable to natural events.

Forest area (% of total land area) (FOREST) – Any land area, at least 5 meters in place, that is composed of natural or planted stands of productive and unproductive trees. This excludes trees in agricultural plantations, urban parks, and gardens.

$$\frac{Forest\ Area}{Total\ land\ area} \times 100$$

In this study, forests are regarded as natural protective mechanism against extreme natural events. It is expected that the percentage of forest area is inversely related to vulnerability.

GDP allotted to health expenses (% of GDP) (HEALTHEXP) – This is the ratio of the sum of private and public health expenditure to GDP. The sum includes the preventive and curative coverage of health services, family planning activities, nutrition activities, and emergency aid.

$$\frac{Health\ expenses}{GDP} \times 100$$

In this study, it is adapted as the measure of accessibility to health care. It is inversely related to vulnerability.

Gross domestic product per capita (US dollars) (GDPPC) – GDP per capita is the gross domestic product divided by midyear population. The World Bank explains GDP as “the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources."

$$\frac{GDP}{Total\ population}$$

In this study, GDP per capita explains the relationship of income to a country's vulnerability. Low GDP per capita makes the poor more unable to survive a natural event while high GDP per capita makes the well-off lose more economically. In general, countries that have higher GDP per capita are less vulnerable than those with low GDP per capita.

Population ages 15-64 (% of total population) (WORKAGE) **-** This tells the percentage of the population from age 15 to 64.

$$\frac{Population\ ages\ 15\ to\ 64}{Total\ population} \times 100$$

In this study, it is expected that the population ages 15-64 is less vulnerable than the population of children and elderly. Hence, this variable is expected to be inversely related to a country's vulnerability.

World giving index (score in %) (WGI) – This calculated as the combined average of the proportion of people who reported one or more of the following in the month before the interview: helping a stranger (A), donating money (B), and volunteering time (C).

$$\text{WGI} = \frac{1}{3}(A + B + C)$$

In this study, the world giving index is used to quantify people's responsiveness to the needs of others. It is expected to be inversely related to vulnerability since generosity and volunteerism help build stronger coping mechanism, which balances the loss experienced by those severely affected. However, relief operations may put the volunteers closer to danger.

The succeeding indices are scores from 1 to 7, with 7 depicting the most desirable outcome. The scores are all continuous for each country since they are weighted averages. Indicators marked with asterisk are not derived from the surveys and have to be converted to 1-7 scale to be consistent with the survey results (for details, refer to The Global Competitiveness Report 2017-2018). The unit of the said indicators prior to being converted to 1-7 scale is displayed next to them. Some indicators (with alphabet variable assignments) are assigned ½ coefficients to show that they are related to and hence, used in two different pillars. The half-weights assigned avoid double-counting.

Goods market efficiency index (score from 1 to 7) (MARKET) – This measures competition and quality of demand conditions. Competition can either be domestic or foreign. Domestic competition is quantified through the intensity of local competition (A), extent of market dominance (B), effectiveness of anti-monopoly policy (C), effect of taxation on incentives to invest (D), *total tax rate (unit: % profits) (E), *number of procedures required to start a business and time required to start a business (unit: days) (F), and agricultural policy costs (G). Foreign competition is measured through the prevalence of trade barriers (H), *trade tariffs (unit: % duty) (I), prevalence of foreign ownership (J), business impact of rules on FDI (K), burden of customs procedures (L), and *imports (unit: % GDP) (M). This index also measures the quality of demand conditions through the degree of customer orientation (N) and buyer sophistication (O). For the weights of domestic and foreign-competition-related-aggregate, it should be noted that domestic competition is the sum of consumption (P), investment (Q), government spending (R), and exports (S), while foreign competition is equal to imports (T). This leads to the formula for the weights below.

$$MARKET = 0.67\left\{w_1\left[\frac{1}{7}(A+B+C+D+E+F+G)\right] + w_2\left[\frac{1}{6}(H+I+J+K+L+M)\right]\right\} + 0.33\left[\frac{1}{2}(N+O)\right]$$

where

$$w_1 = \frac{\mathrm{P} + \mathrm{Q} + \mathrm{R} + \mathrm{S}}{\mathrm{P} + \mathrm{Q} + \mathrm{R} + \mathrm{S} + \mathrm{T}} \;\&\; w_2 = \frac{\mathrm{T}}{\mathrm{P} + \mathrm{Q} + \mathrm{R} + \mathrm{S} + \mathrm{T}}$$

In this study, the goods market efficiency is used as an indicator for a facet of the economy. It may be expected that goods market efficiency is inversely related to vulnerability.

Infrastructure index (score from 1 to 7) (INFRAS) – This index describes the transport infrastructure through the quality of overall infrastructure (A), quality of roads (B), quality of railroad infrastructure (C), quality of port infrastructure (D), quality of air transport infrastructure

(E), and *available airline seat kilometers (unit: millions per week) (F). It also describes the electricity and telephony infrastructure through the quality of electricity supply (G), *mobile-cellular telephone subscriptions (unit: per 100 population) (H), and *fixed-telephone lines (unit: per 100 population) (I).

$$INFRAS = \frac{1}{2}\left[\frac{1}{6}\left(A + B + C + D + E + F\right)\right] + \frac{1}{2}\left[\frac{1}{3}\left(G + \frac{1}{2}H + \frac{1}{2}I\right)\right]$$

In this study, low infrastructure index score equates to fragile infrastructures, dilapidated transport routes, unsafe power grids, and other related anomalies. Hence, infrastructure index is expected to be inversely related to a country's vulnerability.

Innovation index (score from 1 to 7) (INNOV) - This index summarizes measures for the following: capacity for innovation (A), quality of scientific research institutions (B), company spending on R&D (C), university-industry collaboration in R&D (D), government procurement of advanced technology products (E), availability of scientists and engineers (F), *PCT patent applications (unit: applications per million pop.) (G), and intellectual property protection (H).

$$INNOV = \frac{1}{8}\left(A + B + C + D + E + F + G + \frac{1}{2}H\right)$$

In this study, high innovation index score is seen to lessen a country's vulnerability.

Institutions index (score from 1 to 7) (INSTIT) – This variable provides a measure on concepts related to public and private institutions. To describe public institutions, property rights are explained through the extent of protection to property rights (A) and to intellectual property rights (B), ethics and corruption through diversion of public funds (C), public trust in politicians (D), and irregular payments and bribes (E), undue influence through judicial independence (F) and favoritism in decisions of government officials (G), public sector performance through wastefulness of government spending (H), burden of government regulation (I), efficiency of legal framework in settling disputes (J), efficiency of legal framework in challenging regulations (K), and transparency of government policymaking (L), and security through business costs of terrorism (M), business costs of crime and violence (N), organized crime (O), and reliability of police services (P). To describe private institutions, corporate ethics are explained through ethical behavior of firms (Q) and accountability is explained through strength of auditing and reporting standards (R), efficacy of corporate boards (S), protection of minority shareholders' interests (T), and *strength of investor protection (unit: 0-10 where 10 is best) (U).

$$INSTIT = \frac{3}{4}\left\{\frac{1}{5}\left[\frac{1}{2}\left(A + \frac{1}{2}B\right) + \frac{1}{3}(C + D + E) + \frac{1}{2}(F + G) + \frac{1}{5}(H + I + J + K + L) + \frac{1}{4}(M + N + O + P)\right]\right\} + \frac{1}{4}\left\{\frac{1}{2}\left[Q + \frac{1}{4}(R + S + T + U)\right]\right\}$$

Low institutions index score characterizes slow process of economic development. In this study, institutions index is used to measure goodness of governance. Weak governance is said to intensify a country's vulnerability.

Technological readiness index (score from 1 to 7) (TECH) – This summarizes measures for technological adoption and ICT use. The former has the following components: availability of latest technologies (A), firm-level technology absorption (B), and Foreign Direct Investment and technology transfer (C). The latter has the following components: * individuals using the Internet (unit: % population) (D), *fixed-broadband Internet subscriptions (unit: per 100 population) (E), *international Internet bandwidth (unit: kb/s per internet user) (F), *active mobile-broadband subscriptions (unit: per 100 population) (G), *mobile-cellular telephone subscriptions (unit: per 100 population) (H), and *fixed-telephone lines (unit: per 100 population) (I).

$$TECH = \frac{1}{2}\left[\frac{1}{3}(A + B + C)\right] + \frac{1}{2}\left[\frac{1}{6}\left(D + E + F + G + \frac{1}{2}H + \frac{1}{2}I\right)\right]$$

In this study, technological readiness is used to describe developments in information technology and other similar fields. Seen as an avenue towards better disaster preparedness and management mechanism, higher technological readiness index score is associated to lesser vulnerability.

b. MODEL SPECIFICATION

The proposed model is a multiple linear regression with vulnerability index as the dependent variable and 13 indicators as independent variables.

$$
\begin{aligned}
VUL = \beta_0 + \beta_1 EXPOSURE + \beta_2 EDUC + \beta_3 HEALTHEXP + \beta_4 WGI + \beta_5 FOREST \\
+ \beta_6 FEMALE + \beta_7 GDPPC + \beta_8 WORKAGE + \beta_9 INSTIT + \beta_{10} INFRAS \\
+ \beta_{11} MARKET + \beta_{12} TECH + \beta_{13} INNOV + \varepsilon
\end{aligned}
$$

c. MODEL ASSUMPTIONS

- All tests and variable selection processes have 0.05 level of significance.
- The relationship between vulnerability and the independent variables are linear and subject to random error.
- Error terms are assumed to be normal, homoscedastic, and uncorrelated in the absence of sufficient evidence to conclude otherwise.
- Independent variables are assumed linearly independent in the absence of sufficient evidence to conclude otherwise.
- There is no autocorrelation between observations in the absence of sufficient evidence to conclude otherwise.

IV. RESULTS AND DISCUSSIONS

Initial Results in Multiple Linear Regression

All 13 variables are regressed against the variable **VUL**. The initial model has an R^2 value of 0.9677, meaning 96.77% of the variation of the dependent variable can be explained by the 13 predictor variables. But only 8 of them (**EDUC**, **GDPPC**, **INFRAS**, **MARKET**, **TECH**, **WGI**, **WORKAGE**) are significant to the model.

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	13	19811	1523.95041	220.94	<.0001
Error	96	662.16977	6.89760		
Corrected Total	109	20474			

Root MSE	2.62633	**R-Square**	0.9677
Dependent Mean	46.29655	**Adj R-Sq**	0.9633
Coeff Var	5.67284		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	93.60500	9.39913	9.96	<.0001
EDUC	EDUC	**1**	-31.70379	3.79021	-8.36	<.0001
EXPOSURE	EXPOSURE	**1**	-0.02644	0.03215	-0.82	0.4129
FEMALE	FEMALE	**1**	0.00471	0.12878	0.04	0.9709
FOREST	FOREST	**1**	0.00043877	0.01459	0.03	0.9761
GDPPC	GDPPC	**1**	-0.00009852	0.00002530	-3.89	0.0002
HEALTHEXP	HEALTHEXP	**1**	-0.02298	0.11008	-0.21	0.8351
INFRAS	INFRAS	**1**	-2.33280	0.64872	-3.60	0.0005
INNOV	INNOV	**1**	0.92677	0.79806	1.16	0.2484
INSTIT	INSTIT	**1**	-0.19572	0.78308	-0.25	0.8032
MARKET	MARKET	**1**	2.50512	1.16944	2.14	0.0347
TECH	TECH	**1**	-3.99203	0.78570	-5.08	<.0001
WGI	WGI	**1**	0.10390	0.02856	3.64	0.0004
WORKAGE	WORKAGE	**1**	-0.21658	0.07805	-2.77	0.0066

As expected, the variables **EDUC**, **GDPPC**, **INFRAS**, **MARKET**, **TECH**, **WGI**, and **WORKAGE** are significant to the model since these can be considered as societal indicators related to the vulnerability of a country. On the other hand, we have noticed that variable **HEALTHEXP** is not significant in the model even if it can be a strong indicator of vulnerability of a country. One possible reason is that the percentage of GDP allotted to health might not be a good indicator of the overall quality of health care in a country. For instance, a country might have a high percentage of GDP allocated to health, but if the GDP per capita itself is too low, then a high percentage of GDP allocated to health is not indicative of a good health care quality.

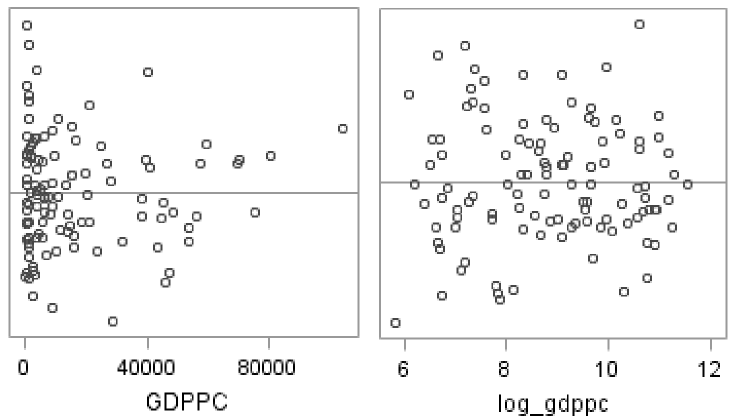
Exposure is also not a significant predictor. This shows that being highly exposed to disasters does not automatically mean that a country is highly vulnerable. Take the case of Philippines and Japan. Both countries have relatively high exposure indices. But their vulnerabilities are much different from one another. Japan has taken huge steps for their disaster preparedness programs in the last few years. Their basic disasters prevention law is being continuously revised. Public-private partnerships (PPPs) also helps the Japanese government to manage disaster risk through investments from the private sector. Thus, even if they have a very high exposure to natural disasters, their vulnerability is one of the lowest.

COUNTRY	EXPOSURE	VUL
Philippines	52.46%	52.78%
Japan	45.91%	29.33%

The variables **INSTIT** and **INNOV** are not significant even if they have strong correlation with the dependent variable. By nature, the economic indicators are interrelated - they tend to reinforce each other. It can be seen from the correlation matrix in appendix that **INSTIT** and **INNOV** have high Pearson R correlation coefficient in the variables **EDUC**, **GDPPC**, **INFRAS, MARKET**, and **TECH**. The information from the two mentioned variables has already been duplicated by the other significant predictor variables. For example, the index for innovation, **INNOV**, is highly correlated with the index for infrastructures, **INFRAS**, since a high R&D capability can lead to availability of quality transport, communications, and energy infrastructures. Notice that R&D capability also depends on the GDP per capita of a certain country. Thus, interrelation among the independent variables are evident in this model.

Variable Transformation

The residual plots of each of the independent variables reveal a recognizable pattern under the **GDPPC** variable. Thus, a log transformation was done on **GDPPC**, and was named as **LOG_GDPPC**.



It is not surprising that the residual plot of the variable **GDPPC** looks like the above since it is a money related variable. There are some countries that have a relatively high GDP compared to the majority. Example of these countries are Luxembourg, Switzerland, and USA. Luxembourg has the highest GDP per capita in the dataset with $104103.03. Given their small population, majority of their workforce are employed in services, primarily in the banking and industrial sectors, in which their economy is highly dependent on.

Overall, the distribution of financial data is typically skewed, and if this will not be address properly, it might lead to a problem in regression analysis. Note that after log transforming the variable, the appropriate interpretation of the coefficient of **LOG_GDPPC** must be done.

Variable Selection

The automatic variable selection procedures (forward selection, backward elimination, and stepwise selection) yielded the same result. Below is the result of the backward elimination.

Backward Elimination: Step 7

Variable HEALTHEXP Removed: R-Square = 0.9688 **and** C(p) = 8.2179					
Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	6	19835	3305.78849	533.03	<.0001
Error	103	638.79413	6.20188		
Corrected Total	109	20474			

Variable	**Parameter Estimate**	**Standard Error**	**Type II SS**	**F Value**	**Pr > F**
Intercept	112.98426	3.25926	7452.82660	1201.70	<.0001
EDUC	-29.30334	3.30803	486.65373	78.47	<.0001
LOG_GDPPC	-2.86477	0.49875	204.61348	32.99	<.0001
INFRAS	-1.22450	0.54040	31.84234	5.13	0.0255
TECH	-2.27507	0.72791	60.58360	9.77	0.0023
WGI	0.10795	0.02364	129.33553	20.85	<.0001
WORKAGE	-0.15862	0.05389	53.73473	8.66	0.0040

Summary of Backward Elimination								
Step	**Variable Removed**	**Label**	**Number Vars In**	**Partial R-Square**	**Model R-Square**	**C(p)**	**F Value**	**Pr > F**
1	EXPOSURE	EXPOSURE	12	0.0001	0.9712	12.3594	0.36	0.5502
2	INNOV	INNOV	11	0.0002	0.9710	10.9790	0.62	0.4316
3	FOREST	FOREST	10	0.0002	0.9707	9.7612	0.79	0.3762
4	FEMALE	FEMALE	9	0.0002	0.9705	8.5274	0.78	0.3805
5	INSTIT	INSTIT	8	0.0004	0.9701	8.0139	1.51	0.2222
6	MARKET	MARKET	7	0.0005	0.9696	7.7067	1.71	0.1940
7	HEALTHEXP	HEALTHEXP	6	0.0008	0.9688	8.2179	2.52	0.1156

After using Backward Elimination with 0.05 level of significance to stay, 6 significant predictor variables were left in the model. The predictor **MARKET** was not included in the selected variables even if in the initial results, it is significant in the model. This might be again due to multicollinearity. Since the market efficiency index, **MARKET**, is used as an indicator of a facet of the economy, it is also expected to be related to the other economic predictor variables that are retained in the model. How well a country could produce the right kind of products and how certain goods are effectively involved in trade depends on the availability of quality infrastructures and the GDP per capita.

The remaining variables in the model were checked for multicollinearity.

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	**1**	112.98426	3.25926	34.67	<.0001	0
EDUC	EDUC	**1**	-29.30334	3.30803	-8.86	<.0001	5.67885
LOG_GDPPC		**1**	-2.86477	0.49875	-5.74	<.0001	9.67148
INFRAS	INFRAS	**1**	-1.22450	0.54040	-2.27	0.0255	7.77648
WGI	WGI	**1**	0.10795	0.02364	4.57	<.0001	1.14267
WORKAGE	WORKAGE	**1**	-0.15862	0.05389	-2.94	0.0040	1.72340
TECH	TECH	**1**	-2.27507	0.72791	-3.13	0.0023	15.26287

Collinearity Diagnostics					
Number	**Eigenvalue**	**Condition Index**	**Proportion of Variation**		
			Intercept	**EDUC**	**LOG_GDPPC**
1	6.82644	1.00000	0.00011092	0.00021667	0.00006082
2	0.09238	8.59623	0.00427	0.00907	0.00024240
3	0.05973	10.69029	0.02650	0.00008788	0.00052191
4	0.01151	24.35557	0.00472	0.49750	0.00000983
5	0.00508	36.65850	0.04475	0.36779	0.07533
6	0.00272	50.13840	0.55745	0.11560	0.01529
7	0.00215	56.37872	0.36220	0.00973	0.90855

Proportion of Variation			
INFRAS	**WGI**	**WORKAGE**	**TECH**
0.00022219	0.00163	0.00009944	0.00011126
0.01528	0.47911	0.00083470	0.00818
0.01386	0.42679	0.01759	0.00674
0.37661	0.02529	0.00651	0.00124
0.37766	0.03266	0.07787	0.38896
0.21455	0.03397	0.89672	0.18863
0.00182	0.00055500	0.00037409	0.40614

The variance inflation factor of the variable **TECH** (15.26287) exceeded the cutoff of 10. There are also eigenvalues with condition index greater than 30, which indicates a presence of multicollinearity. The technological readiness index, **TECH**, as a measure of developments in information technology, is expected to be highly related to the country's GDP per capita. **TECH** is also related to the infrastructure index since both involve mobile cellular telephone subscriptions indicator and fixed telephone lines indicator.

To address the problem, we tried to center the values under the variable **TECH**. But centering didn't work in this case. So, we have checked if the model could be expressed by fewer variables. By R-square selection method, the model without the **TECH** variable still has an R^2 of 0.9658, which is very close to 0.9688, the R^2 of the model with 6 predictors. Thus, we chose the simpler model without the **TECH** variable.

After the selection of variables, the proposed model is:

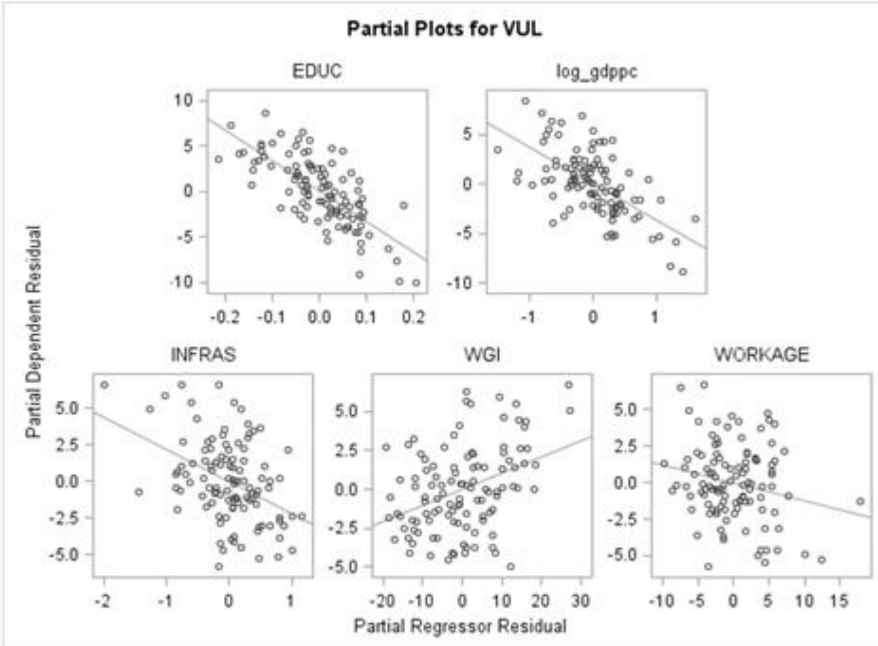
$$VUL = \beta_0 + \beta_1 EDUC + \beta_2 LOGGDPPC + \beta_3 INFRAS + \beta_4 WGI + \beta_5 WORKAGE + \varepsilon.$$

Note that joint correlation can still exist with the remaining predictor variables in the proposed model. In the next section, the joint correlation will be checked if it can affect the model building process.

Diagnostic Checking and Validation of Assumptions

The assumption of linearity of the regression function was verified through the residual plots. The plots of residuals against each predictor variables contain no patterns that may indicate departures from linearity.

The normality assumption on the error terms was tested based on the residuals. The large p-values from the available tests indicate that there is no sufficient evidence for the non-normality of the error terms. Hence, the error distribution rarely generate outliers that influence that least squares estimate too much.



Tests for Normality				
Test	**Statistic**		**p Value**	
Shapiro-Wilk	**W**	0.99106	**Pr < W**	0.6912
Kolmogorov-Smirnov	**D**	0.05383	**Pr > D**	>0.1500
Cramer-von Mises	**W-Sq**	0.048766	**Pr > W-Sq**	>0.2500
Anderson-Darling	**A-Sq**	0.306986	**Pr > A-Sq**	>0.2500

We have also checked if there is autocorrelation using Durbin-Watson Test. The value of Durbin-Watson D statistic is near 2, and the value of 1st Order Autocorrelation is near 0. This implies that there is no sufficient evidence of autocorrelation. This is expected since the data is cross-country. The indicators of each country have minimal or almost no effect to the other countries.

Durbin-Watson D	2.144
Number of Observations	110
1st Order Autocorrelation	-0.101

Again, multicollinearity is checked in the model. The results show that there is no variance inflation factor that exceeds 10, which means that there is no significant linear near-dependency among the 5 predictor variables. The remaining economic indicators in the model has tolerable level of dependency with each other. For instance, high GDP per capita does not always mean a high education index since it still depends on the country's priorities on where they will allocate their budget.

Parameter Estimates							
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
Intercept	Intercept	**1**	114.71221	3.34470	34.30	<.0001	0
EDUC	EDUC	**1**	-33.73560	3.11209	-10.84	<.0001	4.63523
LOG_GDPPC		**1**	-3.62900	0.45266	-8.02	<.0001	7.34694
INFRAS	INFRAS	**1**	-2.16674	0.46702	-4.64	<.0001	5.35635
WGI	WGI	**1**	0.10421	0.02458	4.24	<.0001	1.13974
WORKAGE	WORKAGE	**1**	-0.12347	0.05488	-2.25	0.0266	1.64834

The assumption of constant error variance was checked via White's Test (without cross-products). The square of the residuals were regressed on the constant, the original regressors, and their squares. The result is shown below.

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	10	853.00338	85.30034	1.25	0.2720
Error	99	6779.42857	68.47908		
Corrected Total	109	7632.43194			

Root MSE	8.27521	**R-Square**	0.1118
Dependent Mean	6.35798	**Adj R-Sq**	0.0220
Coeff Var	130.15469		

The test-statistic is equal to 12.2980 (computed as nR^2). To reject the assumption of homoscedasticity, the test statistic must exceed $\chi^2_{m,\alpha} = \chi^2_{10,0.05} = 18.3074$, where m is the number of regressors excluding the constant. From the result, we have concluded that there is no sufficient evidence of heteroscedasticity since the test statistic did not exceed 18.3074.

We used leverage for detecting outliers in the model. We have found 5 observations that exceeded the cut-off value 0.10909, computed as $\frac{2p}{n}$, where p is the number of parameters in the model and n is the number of observations. The observations that exceeded the cut-off is listed below.

Obs	Country	Leverage	Cook's D	DFFITS
103	United Arab Emirates	0.23163	0.00785	0.21614
54	Kuwait	0.16408	0.08251	-0.7089
107	Venezuela	0.15741	0.0282	0.41114
64	Mali	0.11876	0.00967	-0.2402
50	Japan	0.11348	3.6E-05	0.01471

One of the possible reasons why United Arab Emirates and Kuwait was detected as an outlier since the proportion of their working age is high. This might be due to a lot of migrant workers in these countries to fulfill their need for skilled manpower. On the other hand, Mali has the smallest proportion of working age in their population. They also have the lowest education index among the 110 countries in the dataset. While Venezuela and Japan may have an unusual combination of predictor values that make them high-leverage observations.

To determine if the outliers are influential or not, we check the Cook's D and DFFITS of the observations. Since there is no observation that has a Cook's D value greater than 0.036364 (computed as $\frac{4}{n}$) and DFFITS value greater than 0.467099 (computed as $2\frac{\sqrt{p}}{n}$), we can retain the observations since they are not influential in affecting the fit of the regression model.

After diagnostic checking and validation of assumptions, we came up with this fitted model:

$$\widehat{VUL_i} = 114.71 - 33.74 * EDUC_i - 3.63 * LOGGDPPC_i - 2.17 * INFRAS_i + 0.10 * WGI_i - 0.12 * WORKAGE_i$$

Root MSE	2.59322	**R-Square**	0.9658
Dependent Mean	46.29655	**Adj R-Sq**	0.9642
Coeff Var	5.60132		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	114.71221	3.34470	34.30	<.0001
EDUC	EDUC	**1**	-33.73560	3.11209	-10.84	<.0001
INFRAS	INFRAS	**1**	-2.16674	0.46702	-4.64	<.0001
LOG_GDPPC		**1**	-3.62900	0.45266	-8.02	<.0001
WGI	WGI	**1**	0.10421	0.02458	4.24	<.0001
WORKAGE	WORKAGE	**1**	-0.12347	0.05488	-2.25	0.0266

V. CONCLUSIONS AND RECOMMENDATIONS

The final model includes five indicators, namely, education index (**EDUC**), log transform of GDP per capita (**LOG_GDPPC**), infrastructure index (**INFRAS**), world giving index (**WGI**), percentage of population ages 15-64 (**WORKAGE**), all of which are significant at 0.05 level. The model has an R^2 of 0.9658 and an adjusted R^2 of 0.9642.

In the final model, education index is inversely related to vulnerability. A high literacy rate suggests that more people will be able to protect themselves more since they can read and understand precautionary measures and warning signs from the media or from their local government. GDP per capita is also inversely related to vulnerability. This can be because countries with high GDP per capita have an ability to allocate higher budget for disaster preparedness and risk reduction programs. Higher GDP per capita also gives a country more means to recover and regain their losses faster.

The proportion of population ages 15-64 and infrastructure index also have a negative relationship with vulnerability. Children and elderly are generally more vulnerable than the working age population, ages 15-64. The higher the population proportion of ages 15-64, the lower the proportion of children and elderly in the population, the lower the vulnerability. Substandard and fragile infrastructures can worsen the impact of natural disasters in a country. Thus, higher infrastructure index lowers the vulnerability score.

Overall, the final model is acceptable since it tends to agree with previous studies conducted about vulnerability. The only surprising result is the effect of World Giving Index since it is expected to have a negative relationship with vulnerability. Though generosity and volunteerism can help build stronger coping mechanism, one possible reason for the positive relationship is that relief operations may put volunteers closer to danger.

There are continuous studies regarding the concept of vulnerability so we cannot say that we have completely included all the possible indicators. To improve the model, future researchers may include more indicators that are not mentioned in this study. Alternative sources of data per indicator may also be used. One may also explore the use of principal component regression to address multicollinearity.

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VII. APPENDIX

PEARSON CORRELATION COEFFICIENTS

Pearson Correlation Coefficients, N = 110							
	EDUC	**EXPOSURE**	**FEMALE**	**FOREST**	**LOG_GDPPC**	**HEALTHEXP**	**INFRAS**
EDUC	1.0000	-0.1270	0.0990	0.1776	0.8772	0.3560	0.8236
EXPOSURE	-0.1270	1.0000	0.1127	0.1958	-0.1180	-0.0407	-0.0672
FEMALE	0.0990	0.1127	1.0000	0.2394	-0.0873	0.2063	-0.0947
FOREST	0.1776	0.1958	0.2394	1.0000	0.1735	0.2176	0.1339
LOG_GDPPC	0.8772	-0.1180	-0.0873	0.1735	1.0000	0.2952	0.8945
HEALTHEXP	0.3560	-0.0407	0.2063	0.2176	0.2952	1.0000	0.3328
INFRAS	0.8236	-0.0672	-0.0947	0.1339	0.8945	0.3328	1.0000
INNOV	0.6362	-0.1107	-0.1019	0.1373	0.7354	0.3640	0.8013
INSTIT	0.5998	-0.1487	-0.2101	0.0310	0.6773	0.3204	0.7837
MARKET	0.6500	-0.0676	-0.1500	0.0897	0.7132	0.2994	0.8246
TECH	0.8936	-0.1344	-0.0111	0.1538	0.9386	0.3663	0.9259
WGI	0.2075	-0.0526	-0.2674	-0.0267	0.2841	0.2946	0.2934
WORKAGE	0.5860	-0.0278	-0.3090	-0.0362	0.5869	-0.0217	0.5828

Pearson Correlation Coefficients, N = 110						
	INNOV	**INSTIT**	**MARKET**	**TECH**	**WGI**	**WORKAGE**
EDUC	0.6362	0.5998	0.6500	0.8936	0.2075	0.5860
EXPOSURE	-0.1107	-0.1487	-0.0676	-0.1344	-0.0526	-0.0278
FEMALE	-0.1019	-0.2101	-0.1500	-0.0111	-0.2674	-0.3090
FOREST	0.1373	0.0310	0.0897	0.1538	-0.0267	-0.0362
LOG_GDPPC	0.7354	0.6773	0.7132	0.9386	0.2841	0.5869
HEALTHEXP	0.3640	0.3204	0.2994	0.3663	0.2946	-0.0217
INFRAS	0.8013	0.7837	0.8246	0.9259	0.2934	0.5828
INNOV	1.0000	0.8782	0.8468	0.7975	0.4439	0.2141
INSTIT	0.8782	1.0000	0.8890	0.7586	0.4369	0.2915
MARKET	0.8468	0.8890	1.0000	0.8133	0.4023	0.4066
TECH	0.7975	0.7586	0.8133	1.0000	0.2927	0.5448
WGI	0.4439	0.4369	0.4023	0.2927	1.0000	0.0445
WORKAGE	0.2141	0.2915	0.4066	0.5448	0.0445	1.0000

RESULTS OF INDIVIDUAL REGRESSION

Variable **EDUC**

Root MSE	4.60558	**R-Square**	0.8881
Dependent Mean	46.29655	**Adj R-Sq**	0.8871
Coeff Var	9.94799		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	98.00962	1.82003	53.85	<.0001
EDUC	EDUC	**1**	-75.16336	2.56721	-29.28	<.0001

Variable **EXPOSURE**

Root MSE	13.68174	**R-Square**	0.0126
Dependent Mean	46.29655	**Adj R-Sq**	0.0034
Coeff Var	29.55241		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	43.67918	2.58681	16.89	<.0001
EXPOSURE	EXPOSURE	**1**	0.18213	0.15544	1.17	0.2439

Variable **FEMALE**

Root MSE	13.76767	**R-Square**	0.0001
Dependent Mean	46.29655	**Adj R-Sq**	-0.0091
Coeff Var	29.73800		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	49.03514	25.06862	1.96	0.0530
FEMALE	FEMALE	**1**	-0.05446	0.49786	-0.11	0.9131

Variable **FOREST**

Root MSE	13.60377	**R-Square**	0.0238
Dependent Mean	46.29655	**Adj R-Sq**	0.0147
Coeff Var	29.38398		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	49.31963	2.27087	21.72	<.0001
FOREST	FOREST	**1**	-0.11199	0.06905	-1.62	0.1078

Variable **GDPPC**

Root MSE	9.03305	**R-Square**	0.5696
Dependent Mean	46.29655	**Adj R-Sq**	0.5656
Coeff Var	19.51128		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	54.38582	1.09529	49.65	<.0001
GDPPC	GDPPC	**1**	-0.00048748	0.00004078	-11.95	<.0001

Variable **HEALTHEXP**

Root MSE	12.97807	**R-Square**	0.1115
Dependent Mean	46.29655	**Adj R-Sq**	0.1033
Coeff Var	28.03249		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	58.47943	3.53285	16.55	<.0001
HEALTHEXP	HEALTHEXP	**1**	-1.67619	0.45528	-3.68	0.0004

Variable **INFRAS**

Root MSE	5.95291	**R-Square**	0.8131
Dependent Mean	46.29655	**Adj R-Sq**	0.8113
Coeff Var	12.85822		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	87.35008	1.97739	44.17	<.0001
INFRAS	INFRAS	**1**	-10.03977	0.46323	-21.67	<.0001

Variable **INNOV**

Root MSE	9.98386	**R-Square**	0.4742
Dependent Mean	46.29655	**Adj R-Sq**	0.4693
Coeff Var	21.56503		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	84.30964	3.96765	21.25	<.0001
INNOV	INNOV	**1**	-10.57789	1.07183	-9.87	<.0001

Variable **INSTIT**

Root MSE	10.32750	**R-Square**	0.4374
Dependent Mean	46.29655	**Adj R-Sq**	0.4322
Coeff Var	22.30727		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	87.17577	4.56882	19.08	<.0001
INSTIT	INSTIT	**1**	-10.12318	1.10482	-9.16	<.0001

Variable **MARKET**

Root MSE	9.76296	**R-Square**	0.4972
Dependent Mean	46.29655	**Adj R-Sq**	0.4925
Coeff Var	21.08789		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	119.20296	7.11596	16.75	<.0001
MARKET	MARKET	**1**	-16.66605	1.61270	-10.33	<.0001

Variable **TECH**

Root MSE	4.45393	**R-Square**	0.8954
Dependent Mean	46.29655	**Adj R-Sq**	0.8944
Coeff Var	9.62043		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	89.84465	1.49420	60.13	<.0001
TECH	TECH	**1**	-10.12961	0.33323	-30.40	<.0001

Variable **WGI**

Root MSE	13.55090	**R-Square**	0.0313
Dependent Mean	46.29655	**Adj R-Sq**	0.0224
Coeff Var	29.26979		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	53.83915	4.23627	12.71	<.0001
WGI	WGI	**1**	-0.22497	0.12033	-1.87	0.0643

Variable **WORKAGE**

Root MSE	10.56654	**R-Square**	0.4110
Dependent Mean	46.29655	**Adj R-Sq**	0.4056
Coeff Var	22.82361		

Parameter Estimates						
Variable	**Label**	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
Intercept	Intercept	**1**	142.94937	11.17861	12.79	<.0001
WORKAGE	WORKAGE	**1**	-1.51204	0.17417	-8.68	<.0001