Global Weather Sensitivity:

A Comparative Study

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Abstract

This study seeks to provide an intuitive and accurate ranking system for weather sensitivity in sixty-eight countries. Results show that countries with extreme temperature variations and high levels of mining and agricultural output are the most sensitive to the weather. Brazil is found to be the most weather sensitive country and Pakistan the least. The US is found to have the largest total weather sensitivity, estimated at $2.5 trillion, or 23 percent of the national economy. Estimates suggest that world output could grow by as much as $258 billion per year if these countries were to hedge their weather risk, roughly estimated to be $5.8 trillion.

1 Introduction

Evidence of global climate change has heightened interest in the relationship between the environment and the economy. Few studies have addressed, however, the effect of small-scale, chronic fluctuations in weather on economic activity. This paper attempts to quantify the sensitivity of the economy to these deviations in sixty-eight countries around the world.

According to this new paradigm, the core results of this paper are based on historical observations of temperature and rainfall, GDP data spanning six years, and elasticity scores linking the weather effect on output to each economic sector. This approach has a number of potential applications. Chronic weather risks are less commonly covered by traditional weather insurance and thus represent a potential growth industry for alternative risk management products such as weather derivatives and index-based insurance. The results of this paper might also be useful for policymakers around the world as a part of their comprehensive risk management strategy. Finally, this study lays a foundation for more detailed future research on weather sensitivity and its weather impact.

2 Literature Review

Given the novelty of this type of research, there is little academic literature to rely on directly. That said, various subsections of weather sensitivity analysis have grown considerably in recent years as increased awareness of global climate change has inspired volumes of research. This literature review will therefore be divided into two categories, one for weather sensitivity research and the other for research related to climate change.

2.1 Weather Sensitivity

The most widely cited study on the weather sensitivity of various economic sectors is Dutton's "Opportunities and Priorities in a New Era for Weather and Climate Services" [2]. Dutton estimates that slightly more than thirty percent of the US economy is sensitive to the weather but does not clearly define what this means. His analysis is merely subjective, and does not provide a good framework for comparing or concretely quantifying the weather sensitivity of various sectors or countries.

Larsen's 2006 report, "An Evaluation of the Sensitivity of US Sectors to Weather," seeks to rigorously determine the subjective estimates made by Dutton [6]. Larsen econometrically estimates the impact of weather on economic output in 11 sectors using a transcendental logarithmic production function (TRANSLOG). His results vary by sector and by region, suggesting that weather sensitivity is not geographically uniform. Aggregate sensitivity values in dollars are found using Monte-Carlo simulations of each sector and the economy as a whole. Monte-Carlo simulations were used to build estimates of the mean and range of economic output due to weather variability based on ten-thousand draws of given weather variables. The difference between the minima and maxima of these ranges is assumed to reflect the total weather sensitivity of the economy or sector. Larsen's results form the core of the current study as they represent the only complete cross-sector statistical analysis of weather sensitivity.

Though the literature is lacking in coherent cross-sectional studies of weather sensitivity, a number of studies have estimated the effect of the weather on particular sectors (see, for example, [4]; [3]; and [11]). Larsen [6] provides a good overview of many of these studies, so we will only briefly review them here. One study of note is from Subak et al that assesses the impact of weather fluctuations on the tertiary sectors of the UK economy in a particular year [10]. Selecting 1995 as a year exhibiting abnormally high temperatures, the authors perform regression analysis using output residuals as the dependent variables and climatic measures as the independent variables. What distinguishes their study from others is its completeness and scope, as it deals with a number of the tertiary sectors of the economy, including energy consumption, tourism, construction, health, and finance, insurance, and real estate (FIRE).

Tol [12] did a comparable study, analyzing the weather's impact on tourism, finance, water consumption, energy consumption, and agriculture in the Netherlands. A unique addition of this paper is a survey of individuals' perceptions of the relationship between weather and the behavior of tourists. The study found that people in the Netherlands are not aware of behavioral changes due to the weather, but that such changes are common. In general, Tol's study finds a statistically significant but relatively small weather impact on the economy, and differentials in the size and direction by sector. Though Tol's analysis is in-depth, it does not provide a simple framework for comparing the weather sensitivity of sectors, and thus cannot be used for extrapolative purposes.

2.2 Climate Impact

Although not directly related to the current study, it is worth noting some of the impact research related to climate change. The IPCC's 2007 report provides the best overall assessment of the potential impacts of climate change [5]. Robert Mendelsohn of Yale University has published a number of papers using a Global Impact Model (GIM) to assess the distribution of climate change impacts in various countries ([7]; [8]; [9]). The GIM combines three types of data: climatic projections, sectoral data, and climate response functions. In the breadth of his research, Mendelsohn makes two key claims: first, that the impacts of climate change will be regionally distributed; and second, that the distribution of these impacts will disproportionately damage poor countries [9].

A number of recent studies attempt to develop these claims. For example, a paper by Melissa Dell, Benjamin Jones and Benjamin Olken of the National Bureau of Economic Research finds that changes in temperature and precipitation have had a measurable impact on economic growth over the last fifty years in poor countries but not in rich ones [1]. Though these climate impact studies do not provide a framework for small-scale weather perturbations, they offer several methodologies for translating climate events into economic variables, and provide useful results from around the world. In that respect, Mendelsohn's GIM, which relates climatic variables to economic ones with sectoral GDP data and climate response functions, most closely resembles the methods used in this study.

2.3 Weather Sensitivity

Weather sensitivity has no formal definition, and has been presented differently in many different papers. Dutton defines weather and climate risk as "the possibility of injury, damage to property, or financial loss owing to severe or extreme weather events, unusual seasonal variations such as heat waves or droughts, or long-term changes in climate or climate variability" [2]. Larsen simply defines weather sensitivity as the degree of economic impact in a sector or economy determined by weather variables [6]. For the purposes of this study, since we are estimating weather effects rather than modeling them, weather sensitivity will be defined as the relative potential effect of weather on a country's economy. It should be noted that the 'Weather Sensitivity Score' we present is unitless, and should be used only to compare relative weather sensitivity between countries.

Many studies have distinguished between weather impact and climate impact. Climate traditionally refers to weather over time, and thus interactions between the climate and the economy can be quite different from interactions between the economy and weather. Climatic changes, according to Mendelsohn, can affect countries in different ways based on their starting climate. For example, colder countries may benefit from global warming while hot ones will not [7]. Weather, on the other hand, is much more event-specific. It is important to note that the interactions described in this paper refer to weather and not to climate.

Finally, in the course of this paper we present separate definitions of weather sensitivity and weather risk. Weather sensitivity refers to the absolute affect of weather on economic output, whether positive or negative. Weather risk refers to only those weather effects that are negative.

3 Methodology

Weather sensitivity rankings were calculated using weighted products of three types of data: country GDP by sector, weather observations by country, and weather elasticity by sector.

3.1 Data and Sources

Economic data was accessed from Euromonitor International in the form of GDP by origin for the years 2002-2007. Nine super-sectors were included in this data: agriculture; mining; manufacturing; utilities; construction; trade, restaurants and hotels; transport, storage and communications; finance, insurance, and real estate; and community services. An 'other' category, accounting for an average of 3% of GDP, was also included in the original dataset, but was excluded in this analysis due to the lack of any understanding of its weather sensitivity. In order to ensure that annual fluctuations did not bias the results, sectoral data was averaged over the six years available, and was presented as a percentage of total GDP. The primary limitation on the scope of analysis was the availability of GDP data, which was available for only 73 countries. Percent GDP data for the 68 countries considered in this analysis is found in Table 6.

Weather data was accessed from the National Environmental Satellite, Data, and Information Service, which provides daily weather data for most of the countries of the world. As with GDP data, quality and scope of weather data was highly irregular by region and degree of economic development. A number of techniques were used to clean the data: weather stations missing more than 20% of data points were excluded from the analysis. Only weather stations with at least 10 years of data history were included. Data reporting an unusual number of repeated zeroes, extremely low precipitation values, or highly erratic and improbable precipitation values were excluded. Finally, where data was missing, it was replaced with the average value for that day over all of the available years. These data cleansing techniques led to some countries having very few reliable weather stations, which may bias results in data scarce environments.

Weather data was gathered in the form of daily observations of temperature and precipitation for as many years as records were readily available. To make this easily interpretable, data was translated into three categories: annual totals of heating-degree-days (HDDs), cooling-degree-days (CDDs), and precipitation. HDDs and CDDs are quantitative indices that demonstrate daily deviations of daily average temperature from 65 degrees Fahrenheit, considered to be the lowest point for heating and cooling demand in commercial and residential buildings. For example, a day with an average temperature of 75 degrees would represent 10 CDDs. For each weather data type, the mean and standard deviation were calculated, from which the coefficient of variance (CV), or the STDEV/MEAN, was found. Each country's CV value was calculated as the average of all of the weather stations in that country. CV data for each weather variable can be found in Table 7.

Weather sensitivity coefficients, presented as elasticity scores by sector and weather variable, were calculated by Larsen [6]. Elasticities are defined as the estimated change in output to a given sector given a 1% change in a given weather variable (HDD, CDD, or Total Precipitation), and are found by taking the partial derivative of a fitted production model with respect to each weather variable. Though Larsen's coefficients are sign-specific, representing positive and negative impacts on output due to weather behavior, all elasticity values were made positive to represent the total range of weather sensitivity. For example, an elasticity of -0.74 would be interpreted in the same way as an elasticity of 0.74, meaning that a 1 percent change in weather would cause a 0.74 percent change in output. The direction of this change—either positive or negative—is not included in the analysis. Larsen's analysis is based on the United States and is disaggregated by region. In order to fit Larsen's results to the countries considered in this paper, a goodness of fit test was done to match a country to its representative region. Countries were matched to the US region that most resembled it in terms of the percent contribution to GDP of each sector. Of course this is not a perfect technique, and does not account for all discrepancies created from using data based on the United States. When the aggregation of super-sectors used in Larsen's research differed slightly from the ones included in the Eurostat dataset, sectors were combined and averaged, producing results for the nine sectors shown in Table 5.

In light of the biases inherent in applying Larsen's US results to the world, two corrections were included in the analysis: cereal yield per hectare and tourism as a share of exports. Other corrections, including indices of GDP per capita or the density of telecommunications, could have been included, but were discarded in favor of the more direct measures of yield per hectare and tourism intensity. Yield per hectare is considered to be a good proxy for agricultural technology and development, and thus should vary inversely with weather sensitivity. Cereals, which include all types of grains, were included as the representative crop due to the relative importance of cereals to most agricultural economies. Data on cereal yield by hectare was gathered from the FOASTAT database of agricultural variables. It was available for the years 2001-2006, and an average of all available years was used to measure each country's yield. To properly weight the data, the ratio of the mean yield for all countries to each country's yield (YIELD/MEAN) was calculated. This creates a value centered around one, with higher values (meaning more weather sensitivity) corresponding to lower yield per hectare and vice-versa. In cases where data was not available, '1' was used.

Data on tourism as a share of exports was included to correct for the potential extreme sensitivity of the tourism sector to weather fluctuations [11]. Data for both total tourism receipts per year and total exports per year were gathered from Euromonitor International for the years 2002-2007 and then averaged. It is assumed that a higher share of exports in the tourism sector will represent more weather sensitivity. Percentage values were normalized around the mean to reflect this relationship. Correction data for yield and tourism can be found in Table 8.

3.2 Calculations

The general calculation used to determine country sensitivity scores is as follows:

$$\text{Weather Sensitivity} = \sum_{i=1}^{9} (GDP)_i (WV)_i$$

where numbers 1-9 represent the different sectors of the economy, from agriculture to community services. GDP represents the percent GDP of each sector. WV represents weather volatility, and is described by the following equation:

$$\text{WV} = \sum_{i=1}^{9} [CV_{HDD} \times E_{HDD} + CV_{CDD} \times E_{CDD} + CV_{Precip} \times E_{Precip}]_i$$

where E is equal to the elasticity of the given weather variable and CV_{HDD}, CV_{CDD}, and CV_{Precip} refer to the coefficient of variance of the weather variable. Weather elasticity scores are sector specific, so each sector has a weather volatility score. Corrections, which are not shown in the above equations, are industry specific: the ‘yield per hectare’ correction is multiplied by the score for agriculture while the ‘tourism as a share of exports’ correction is multiplied by the score for ‘trade, restaurants, and hotels.’

3.3 Methodological Assumptions

A number of critical assumptions were made in the course of this analysis. First, we assume that sector sensitivity in the United States is an accurate measure of sector sensitivity anywhere in the world. This is unlikely to be true, as different degrees of infrastructural development, different climatic environments, and different methods of production within sectors and between countries will surely create biases in the degree to which an economic sector’s output is affected by the weather. As noted above, data for cereal yield by hectare and tourism and a share of exports are included to partially correct for these biases.

Second, we assume the accuracy of Larsen’s statistical methods used to calculate sector sensitivity. Of particular note is the mining sector, which seems to be much more weather sensitive than other, more obviously weather-sensitive sectors such as agriculture and utilities. This could have many explanations, including correlations between the energy industry and demand for oil products and the extreme short-term price volatility of the oil and mining sectors. Though the direct cause of this sensitivity is unclear, anecdotal reports from the mining industry suggest a strong correlation between weather and mining output. For example, Rio Tinto, the world’s largest mining company, announced in January 2008 that heavy rains forced it to temporarily close its Kestrel mine in Queensland, Australia, which has an average annual output of 3.6 million tons of coal.

Third, we assume that annual CDDs, HDDs, and Total Precipitation values are reasonable to use to determine weather volatility, and are not influenced by seasonal and regional trends. To ensure this, we use the coefficient of variation of each variable, defined as the standard deviation divided by the mean, as the measure of weather volatility. This does not reflect absolute weather trends, which are seasonally and regionally dependent, but the degree of variation of these trends.

Finally, we assume a high correlation between a country's total weather volatility and economic output. This may be a good assumption in some countries and a poor one in others. For example, in countries where the majority of economic activity is clustered in small areas, it may not be reasonable to assume that national averages of weather volatility reflect the conditions in the economically intensive area. However, we make the broad assumption that weather stations are located relatively close to regions with at least some economic activity.

3.4 Total Weather Sensitivity

As a corollary to this general analysis, we estimated the total weather sensitivity in US dollars of each country. The methodology to do this is simpler than for the core results. We simply applied the results from Larsen's Monte-Carlo simulation of the US, shown in Table 2, to each sector of each country. Again, where Larsen's sectors do not correspond with the ones used in the Euromonitor dataset, multiple sectors were aggregated and averaged. These ranges, divided by the total GDP of each US sector, reflect the percent of each sector that is weather sensitive. Percentages are multiplied by the dollar value of each sector for each country, averaged over the period 2002-2007, to produce the total weather sensitivity of each sector in US dollars. The sum of these values is presented as the total weather sensitivity of each country:

$$\text{Total Weather Sensitivity} = \sum_{i=1}^{9} (Y)_i (S)_i$$

where Y is the average output of each sector in dollars. S refers to the percent values found in Larsen [6].

3.5 Weather Hedging and Economic Growth

Finally, we set up a model to estimate the potential benefit to each country from hedging their weather risk. This is an approximation, but provides a good framework for managing risk:

$$\text{Net Growth w/ Hedging} = CAR \times eROI - Premium$$

where CAR is capital-at-risk, defined as the difference between the mean and the minimum values from Larsen's Monte-Carlo simulation by sector times each country's sensitivity score. The sensitivity score is adjusted so that the US equals 1, reflecting the fact that Larsen's range data is based on the US. Expected return on investment (eROI) is a six-year average of economic growth by sector. This reflects the potential economic loss to each country due to weather variability. Table 4 shows each country's total CAR values. The premium for each country is the product of the CAR and a set premium rate, set as 5% of the sum of the CV values for all weather variables:

$$\text{Premium} = 0.05 \times (CV_{HDD} + CV_{CDD} + CV_Precip) \times CAR$$

In cases where expected growth from hedging was negative, it was assumed that the sector would not manage its weather risk, and growth was set to zero.

4 Results and Discussion

4.1 Weather Sensitivity Scores

Table 1 shows the weather sensitivity results for the sixty-eight countries included in this study. The scores in Table 1 are presented with and without corrections included in order to show the effect of the corrections on various countries. Each country is given a rank between 1 and 68, with 1 being the most weather sensitive and 68 the least. Figure 1 shows the top ten countries ranked by their sensitivity scores.

Figure 1: Ten Most Weather Sensitive Countries

Country	**Sensitivity Score**	**Rank**
Brazil	15.73	1
Thailand	14.49	2
Ecuador	8.41	3
Norway	8.36	4
Kuwait	8.21	5
Philippines	5.81	6
Indonesia	5.64	7
Saudi Arabia	5.09	8
Canada	4.88	9
Peru	4.85	10

Sensitivity scores represent the numeric solution to the calculations detailed in section 3.2. It should be noted that these are unit-less, and do not correspond to any monetary risk value. Rather, they reflect the relative weather sensitivity of different countries. For example, Brazil, with a sensitivity score of 15.73, is shown to be the most weather sensitive economy, and Pakistan, with a score of roughly 0.58, the least. This means that a dollar in Brazil should be approximately 30 times more weather sensitive than a dollar in Pakistan; a dollar in Pakistan should be slightly less than two-thirds as weather sensitive as a dollar in the United States, with a weather sensitivity score of 0.85. These scores have implications for the economies that they represent, but should not be interpreted as an absolute measure of risk.

The two most weather sensitive countries are Brazil and Thailand, with sensitivity scores of 15.73 and 14.49, respectively. Ecuador, with a sensitivity score of 8.41, is the third most weather sensitive country. All of these countries have very high CV_{HDD} values—3.4, 2.49, and 2.7, respectively—representing extreme fluctuations in cool days. For comparative purposes, the average of all CV_{HDD} values was 0.36; Brazil, Thailand, and Ecuador, are clear anomalies in the data set. Brazil, Thailand, and Ecuador all have average mean HDD values close to zero, which naturally inflates the CV, which is defined as the standard deviation divided by the mean. This bias, however, is partially confirmed by anecdotal evidence: in 1975, for example, as much as 70 percent of Brazil's coffee production was lost due to freezing [1]. It seems reasonable to suggest that tropical climates, and therefore tropical crops, would be more sensitive to cold weather fluctuations than temperate climates.

Another standout from the results are the high scores of the included OPEC countries: Kuwait, Saudi Arabia, and the United Arab Emirates. In contrast to Brazil, Ecuador, and Thailand, whose scores are predominantly driven by weather volatility values, the scores of the OPEC countries are predominantly driven by the size of the mining economy. Mining, which has the highest elasticity value of any sector, comprises 35%, 45%, and 46% of the economies of

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[1] see page 45, Interhemispheric Climate Linkages, ed. Vera Markgraf, Academic Press, 2001

the United Arab Emirates, Kuwait, and Saudi Arabia, respectively. Norway, where mining comprises 25% of GDP, also scores highly, ranking 4th in the total sensitivity scores. As mentioned above, there is some doubt in the accuracy of Larsen's elasticity values for the mining sector. Again, however, anecdotal evidence from the world's largest mining company, Rio Tinto, suggests that weather plays a key role in global production.

A few observations stand out from an analysis of the results in Table 1. First, the correlation between level of economic development and weather sensitivity is surprisingly weak. A simple r-squared test of sensitivity scores and the UN Human Development Index returned a value of 0.05, which is too small to assume any sort of statistically significant correlation. There are a number of intuitive reasons to believe that economic development would have some impact on weather sensitivity: poorer countries tend to be more dependent on agriculture and tourism, sectors that are highly weather sensitive; and less developed countries could likely have a weaker infrastructure when confronting weather risks; also, it seems plausible that countries with high degrees of weather variability would confront more obstacles to developing their economies and would be generally poorer. But our results do not substantiate these claims.

A second observation is the small but significant impact of corrections on sensitivity scores. Though most country rankings did not change much with the inclusion of corrections, some countries moved significantly. Morocco and Tunisia, the two North African countries included in the study, moved from 49th to 29th and from 52nd to 36th, respectively, when corrections were added. Other countries highly affected by the inclusion of corrections were Bolivia and Kazakhstan, which moved from 25th to 19th and from 37th to 27th, respectively. All of these countries exhibit yield per hectare values far below the country mean, and therefore correction scores far above the mean. Given the concerted movement of Morocco and Tunisia, countries very similar in terms of economy and geography, it seems reasonable to suggest that correction values correspond to real structural differences between countries.

Finally, there is little to no correlation between the relative sensitivity scores found in Table 1 and the total weather sensitivity scores found in Table 3. This is not surprising, as total scores are based predominantly on the size of the country's GDP and not on weather volatility. The United States, the largest economy in the world, has the largest total weather sensitivity, valued at roughly $2.5 trillion, but a small weather sensitivity score. In contrast, Bolivia, which has the lowest total weather sensitivity, valued at roughly $2 billion, ranks 20th in relative weather sensitivity. It should be noted that countries with small total weather sensitivity values can still be heavily affected by the weather in relative terms. This is particularly relevant in developing countries, where large percentages of the population live close to subsistence levels. Risk management strategies that protect against weather-related fluctuations in economic output can potentially provide a crucial social safety net in places where none other exists.

4.2 Growth from Weather Hedging

Table 4 shows the total capital-at-risk (CAR) for all sixty-eight countries and their expected economic growth from hedging all of their CAR. These results correspond to the calculations in section 3.5. Note that in some cases the CAR is greater than the total weather sensitivity shown in Table 3. This is due to the fact that the CAR is a function of sectoral sensitivity and the sensitivity scores shown in Table 1, while the total weather sensitivity is a function only of sector sensitivities. An estimate of the percent growth for each country is also included. In absolute terms the United States, China, and Russia, are expected to grow the most from weather hedging, and New Zealand, Switzerland, and Finland, the least. Japan is the only country for which it would not be beneficial to hedge its weather risk and its growth is therefore zero. In percentage terms, Kuwait, Azerbaijan, and Saudi Arabia are expected to grow the most, and Italy, Germany, and Switzerland, the least. The total expected growth of all sixty-eight countries is $258 billion, or roughly 1% of their cumulative output.

5 Conclusions

The results of this paper suggest three conclusions: first, weather sensitivity is diverse and heterogeneous, affecting different countries in different ways; second, the benefits to global economic growth from managing weather risk could be substantial; and lastly, future research on this topic will be critical in removing some of the biases inherent in this analysis. Gathering accurate weather and economic data from countries around the world is central to this task. Each of these will be addressed in turn.

The results of this paper show a wide range of weather sensitivities for different countries, from 0.58 in Pakistan to 15.73 in Brazil. This range suggests that weather sensitivity is not uniform, homogeneous, or general, but rather is determined by a wide range of factors and local conditions. These scores, aggregated at the country level, only partially reflect this diversity. Within countries weather conditions vary greatly. This heterogeneity makes the task of managing weather risk at the country level particularly challenging. Assessing the dependence of the economy on industries such as agriculture, mining, tourism, and manufacturing, as well as other industries that are particularly weather sensitive, is a good first step for managing weather risk. A good understanding of how much weather conditions vary in that country is also important. Businesses likely adapt to the climate in which they work; but variations in the weather can make this adaptation extremely costly.

In addition to the clear advantages of managing weather risk at a small scale, weather hedging could have significantly beneficial effects on total global output. Our results in Table 4 suggest that a comprehensive weather hedging strategy for all sixty-eight countries included in this analysis could add approximately \$258 billion to global output per year. This is likely an underestimate of the potential growth due to a comprehensive global weather hedging strategy. First, this number reflects only the sixty-eight countries included in the analysis, which account for just over half the world's GDP. Second, this method assumes that countries hedge all of their CAR for each sector and reinvest in that sector at historical growth rates. It is unreasonable to expect investors will invest in industries with very poor prospects for growth or negative growth—for example, the agricultural industry in South Africa grew at an average rate of -4%. Hedging weather risk will likely allow investors to divert resources into sectors and industries with greater risk, and therefore greater growth opportunities. In countries where financial markets are weak, the introduction of weather risk management products might help the development of local credit channels, which could significantly boost economic growth.

Finally, this paper suggests a number of directions for future research on global weather sensitivity. Two key priorities in this process should be developing reliable databases of historical weather and economic data around the world, and developing a reliable model to measure the weather sensitivity of different businesses, sectors, countries, and regions. This paper's reliance on elasticity data from the US is a clear bias that can be addressed in future work. However, current limitations on the quality and scope of data around the world make this sort of work extremely challenging. Gathering good data is a prerequisite for more detailed analysis of world weather sensitivity. Once the data is available, researchers should explore new models for measuring the weather impact on the economy. More dynamic models that allow for probabilistic relationships between weather and output might better reflect the uncertainties of weather patterns than static, historical models. This paper is a first step in that direction.

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Table 1: Country Sensitivity Scores and Rankings

Country	**SS w/ Corrections**	**Rank**	**SS w/o Corrections**	**Rank**
Argentina	1.45	54	1.43	54
Australia	1.93	41	1.75	42
Austria	2.27	31	2.27	29
Azerbaijan	2.25	34	2.18	32
Belarus	1.72	47	1.67	45
Belgium	2.07	39	2.09	36
Bolivia	3.32	19	2.67	25
Brazil	15.73	1	15.19	1
Bulgaria	1.78	43	1.74	43
Canada	4.88	9	4.88	9
Chile	4.08	14	4.17	13
China	1.75	45	1.77	41
Colombia	3.19	20	3.15	20
Croatia	1.15	62	1.11	61
Cyprus	0.87	66	0.78	67
Czech Rep.	1.85	42	1.86	39
Denmark	3.36	18	3.38	18
Ecuador	8.41	3	7.56	5
Egypt	2.56	25	2.95	24
Estonia	2.12	37	2.09	35
Finland	2.99	24	3.00	23
France	1.65	50	1.66	47

Country	**SS w/ Corrections**	**Rank**	**SS w/o Corrections**	**Rank**
Germany	2.26	33	2.29	28
Greece	1.01	64	0.97	65
Hungary	1.39	57	1.40	55
India	4.65	11	3.83	15
Indonesia	5.64	7	5.78	6
Ireland	3.95	15	3.98	14
Israel	1.38	58	1.37	56
Italy	1.66	49	1.67	46
Japan	1.00	65	1.01	64
Jordan	1.43	55	1.27	57
Kazakhstan	2.51	27	2.08	37
Kuwait	8.21	5	8.22	4
Latvia	2.26	32	2.23	30
Lithuania	1.27	59	1.25	58
Malaysia	1.25	60	1.21	60
Mexico	4.64	12	4.56	11
Morocco	2.32	29	1.58	49
Netherlands	2.09	38	2.12	34
New Zealand	3.64	17	3.73	17
Norway	8.36	4	8.38	3
Pakistan	0.58	68	0.49	68
Peru	4.85	10	4.76	10
Philippines	5.81	6	5.42	7

Country	**SS w/ Corrections**	**Rank**	**SS w/o Corrections**	**Rank**
Poland	2.22	35	2.20	31
Portugal	1.57	52	1.54	53
Romania	2.04	40	2.01	38
Russia	3.92	16	3.82	16
Saudi Arabia	5.09	8	5.12	8
Singapore	1.03	63	1.02	63
Slovakia	2.27	30	2.29	27
Slovenia	1.56	53	1.57	50
South Africa	1.67	48	1.64	48
Spain	1.73	46	1.69	44
Sweden	3.01	22	3.02	22
Switzerland	3.00	23	3.02	21
Taiwan	3.13	21	3.17	19
Thailand	14.49	2	13.61	2
Tunisia	2.13	36	1.56	52
Turkey	1.40	56	1.24	59
Turkmenistan	1.23	61	1.09	62
Ukraine	2.42	28	2.18	33
UAE	4.39	13	4.49	12
UK	1.76	44	1.79	40
USA	0.85	67	0.86	66
Venezuela	1.57	51	1.56	51
Vietnam	2.52	26	2.61	26

Table 2: Range of Weather Sensitivity by Sector

Sector	% Weather Sensitivity
Agriculture	**28%**
Communications	**6%**
Construction	**14%**
FIRE	**19%**
Manufacturing	**74%**
Mining	**30%**
Retail Trade	**13%**
Services	**11%**
Transportation	**22%**
Utilities	**13%**
Wholesale Trade	**11%**

Source: Larsen, 2006

Table 3: Total Weather Sensitivity

Rank	**Country**	**Weather Sensitivity (USD Millions)**	**Total GDP (USD Millions)**	**Percent GDP**
1	**USA**	2,561,828	11,371,436	23%
2	**Japan**	1,192,784	3,657,011	33%
3	**China**	778,271	1,733,710	45%
4	**Germany**	698,038	1,862,793	37%
5	**UK**	467,437	1,748,177	27%
6	**France**	422,070	1,575,538	27%
7	**Italy**	397,464	1,234,405	32%
8	**Spain**	230,704	804,025	29%
9	**Canada**	221,589	887,211	25%
10	**Brazil**	216,530	541,573	40%
11	**India**	179,382	576,350	31%
12	**Russia**	176,112	517,340	34%
13	**Mexico**	171,058	561,116	30%
14	**Australia**	130,116	526,785	25%
15	**Netherlands**	129,019	464,181	28%
16	**Turkey**	96,253	267,281	36%
17	**Indonesia**	90,474	196,116	46%
18	**Switzerland**	88,822	280,535	32%
19	**Taiwan**	84,630	250,632	34%
20	**Sweden**	80,700	242,994	33%
21	**Saudi Arabia**	80,492	305,895	26%

Rank	**Country**	**Weather Sensitivity (USD Millions)**	**Total GDP (USD Millions)**	**Percent GDP**
22	**Belgium**	79,575	262,340	30%
23	**Austria**	69,183	211,382	33%
24	**Poland**	66,230	203,918	32%
25	**Norway**	61,960	226,413	27%
26	**Thailand**	56,681	101,028	56%
27	**Ireland**	51,178	126,106	41%
28	**South Africa**	50,642	149,788	34%
29	**Argentina**	49,496	126,648	39%
30	**Denmark**	49,386	181,433	27%
31	**Finland**	47,350	125,284	38%
32	**Malaysia**	44,598	86,758	51%
33	**Greece**	40,501	167,563	24%
34	**Portugal**	36,333	128,302	28%
35	**UAE**	35,731	112,317	32%
36	**Singapore**	34,887	83,060	42%
37	**Venezuela**	33,141	114,413	29%
38	**Czech Rep.**	32,700	79,426	41%
39	**Pakistan**	28,559	89,526	32%
40	**Colombia**	28,136	89,106	32%
41	**Philippines**	27,452	76,792	36%
42	**Hungary**	25,456	69,691	37%
43	**Romania**	24,129	62,111	39%

Rank	Country	Weather Sensitivity (USD Millions)	Total GDP (USD Millions)	Percent GDP
44	**Israel**	24,093	100,731	24%
45	**New Zealand**	23,538	84,544	28%
46	**Egypt**	22,638	63,301	36%
47	**Chile**	22,490	65,164	35%
48	**Peru**	19,008	58,608	32%
49	**Kuwait**	18,132	66,491	27%
50	**Ukraine**	17,919	52,987	34%
51	**Vietnam**	14,921	38,501	39%
52	**Morocco**	14,022	45,052	31%
53	**Kazakhstan**	13,617	45,736	30%
54	**Slovakia**	11,315	32,596	35%
55	**Slovenia**	8,535	21,384	40%
56	**Croatia**	8,271	24,114	34%
57	**Ecuador**	7,335	30,182	24%
58	**Tunisia**	7,296	20,751	35%
59	**Lithuania**	6,239	17,158	36%
60	**Bulgaria**	6,076	26,391	23%
61	**Turkmenistan**	5,451	10,116	54%
62	**Azerbaijan**	3,679	13,155	28%
63	**Belarus**	3,613	15,054	24%
64	**Latvia**	3,286	12,213	27%
65	**Estonia**	2,906	9,329	31%

Rank	**Country**	**Weather Sensitivity (USD Millions)**	**Total GDP (USD Millions)**	**Percent GDP**
66	**Jordan**	$2,793$	$8,817$	32%
67	**Cyprus**	$2,730$	$11,946$	23%
68	**Bolivia**	$2,131$	$6,890$	31%

Table 4: Capital at Risk and Expected Growth from Hedging

Country	**Capital At Risk (USD Millions)**	**Expected Growth (USD Millions)**	**Percent GDP**
Argentina	18,022	2,795	1.770%
Australia	83,440	3,033	0.557%
Austria	42,281	205	0.078%
Azerbaijan	3,158	1,219	8.994%
Belarus	2,078	399	2.714%
Belgium	46,159	172	0.055%
Bolivia	2,180	118	1.478%
Brazil	795,391	16,396	2.328%
Bulgaria	3,083	148	0.674%
Canada	352,425	9,555	0.997%
Chile	24,844	1,726	2.251%
China	274,186	27,400	1.290%
Colombia	26,816	1,324	1.253%
Croatia	2,682	162	0.542%
Cyprus	964	40	0.306%
Czech Rep.	13,685	427	0.400%
Denmark	50,851	393	0.187%
Ecuador	22,450	897	2.772%
Egypt	16,138	1,311	1.721%
Estonia	1,749	143	1.272%
Finland	32,681	35	0.021%

Country	**Capital At Risk (USD Millions)**	**Expected Growth (USD Millions)**	**Percent GDP**
France	224, 341	973	0.054%
Germany	368, 541	36	0.001%
Greece	15, 699	740	0.397%
Hungary	9, 028	544	0.608%
India	240, 860	13, 604	2.157%
Indonesia	110, 919	6, 630	2.535%
Ireland	44, 882	1, 370	0.812%
Israel	11, 309	232	0.219%
Italy	181, 590	230	0.015%
Japan	334, 617	0	0.000%
Jordan	937	62	0.677%
Kazakhstan	11, 110	2, 727	5.234%
Kuwait	53, 414	10, 093	14.349%
Latvia	2, 352	316	2.244%
Lithuania	2, 091	178	0.814%
Malaysia	11, 778	1, 114	0.942%
Mexico	220, 124	812	0.120%
Morocco	9, 144	255	0.514%
Netherlands	84, 060	788	0.147%
New Zealand	25, 266	21	0.022%
Norway	174, 264	11, 818	4.709%
Pakistan	5, 719	742	0.738%

Country	**Capital At Risk (USD Millions)**	**Expected Growth (USD Millions)**	**Percent GDP**
Peru	26,388	1,277	1.844%
Philippines	38,830	1,167	1.282%
Poland	41,114	664	0.266%
Portugal	17,859	57	0.038%
Romania	11,940	1,721	2.189%
Russia	189,426	34,431	5.433%
Saudi Arabia	142,652	24,939	8.573%
Singapore	7,683	300	0.275%
Slovakia	6,620	345	0.842%
Slovenia	3,115	85	0.298%
South Africa	23,011	1,404	0.761%
Spain	125,230	4,821	0.511%
Sweden	62,189	199	0.066%
Switzerland	69,846	3	0.001%
Taiwan	57,919	302	0.108%
Thailand	145,621	969	0.639%
Tunisia	4,306	222	0.871%
Turkey	34,907	5,042	1.554%
Turkmenistan	1,238	262	2.098%
Ukraine	258	984	1.710%
UAE	1,317	9,254	7.244%
UK	7,186	4,252	0.213%

Country	**Capital At Risk (USD Millions)**	**Expected Growth (USD Millions)**	**Percent GDP**
USA	$820,349$	$37,059$	0.313%
Venezuela	$18,516$	$6,343$	4.973%
Vietnam	$10,659$	$1,017$	2.102%

Table 5: Sector Codes

Sector	**Code**
Agriculture	**1**
Mining	**2**
Manufacture	**3**
Utilities	**4**
Construction	**5**
Trade, Restaurants, Hotels	**6**
Transport, Storage, Communications	**7**
Finance/Insurance	**8**
Community Service	**9**

Table 6: Percent GDP by Sector

Country	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Argentina	11%	7%	24%	2%	5%	14%	9%	15%	15%
Australia	3%	6%	12%	3%	7%	14%	8%	20%	19%
Austria	2%	0%	19%	2%	8%	17%	7%	23%	21%
Azerbaijan	10%	42%	8%	1%	12%	7%	8%	4%	8%
Belarus	9%	0%	32%	0%	8%	11%	11%	6%	11%
Belgium	1%	0%	17%	2%	5%	15%	8%	28%	23%
Bolivia	15%	11%	14%	3%	2%	11%	13%	11%	19%
Brazil	8%	5%	23%	3%	7%	7%	5%	26%	15%
Bulgaria	13%	1%	18%	6%	5%	9%	13%	19%	16%
Canada	2%	8%	15%	3%	6%	11%	8%	23%	25%

Country	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Chile	6%	13%	18%	5%	8%	9%	7%	20%	11%
China	13%	5%	33%	4%	5%	8%	6%	11%	15%
Colombia	11%	6%	16%	5%	6%	11%	8%	15%	21%
Croatia	7%	1%	20%	3%	6%	18%	10%	18%	16%
Cyprus	3%	0%	10%	2%	8%	20%	8%	24%	23%
Czech Republic	3%	1%	26%	4%	7%	15%	11%	17%	17%
Denmark	2%	3%	14%	2%	5%	13%	9%	24%	28%
Ecuador	8%	16%	7%	0%	8%	16%	19%	11%	15%
Egypt	15%	12%	19%	5%	3%	12%	11%	7%	15%
Estonia	4%	1%	17%	3%	7%	16%	12%	23%	16%
Finland	3%	0%	23%	2%	6%	12%	11%	21%	22%
France	2%	0%	13%	2%	6%	13%	6%	32%	25%
Germany	1%	0%	23%	2%	4%	12%	6%	29%	22%
Greece	6%	1%	11%	2%	8%	21%	9%	20%	22%
Hungary	4%	0%	22%	3%	5%	13%	8%	22%	24%
India	18%	3%	16%	2%	7%	17%	9%	14%	6%
Indonesia	15%	8%	29%	1%	6%	16%	6%	9%	11%
Ireland	2%	0%	26%	1%	10%	12%	5%	24%	19%
Israel	2%	2%	12%	2%	5%	12%	6%	24%	28%
Italy	2%	0%	19%	2%	6%	16%	8%	27%	20%
Japan	2%	0%	20%	3%	6%	13%	7%	18%	29%
Jordan	3%	3%	19%	3%	4%	10%	16%	20%	5%
Kazakhstan	7%	16%	12%	2%	8%	13%	12%	20%	9%

Country	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Kuwait	0%	45%	7%	0%	2%	7%	5%	12%	21%
Latvia	4%	0%	13%	3%	6%	21%	15%	18%	19%
Lithuania	6%	1%	22%	4%	7%	19%	13%	13%	16%
Malaysia	9%	14%	31%	3%	3%	13%	6%	7%	7%
Mexico	4%	1%	17%	1%	5%	20%	10%	13%	27%
Morocco	15%	2%	19%	4%	5%	14%	8%	15%	17%
Netherlands	2%	3%	14%	2%	5%	15%	7%	27%	24%
New Zealand	7%	1%	15%	3%	5%	16%	7%	28%	18%
Norway	2%	25%	10%	3%	5%	10%	8%	18%	21%
Pakistan	22%	3%	18%	3%	2%	18%	13%	7%	15%
Peru	7%	10%	16%	2%	6%	18%	8%	24%	8%
Philippines	15%	1%	23%	3%	4%	15%	7%	11%	21%
Poland	5%	2%	18%	4%	6%	20%	7%	18%	19%
Portugal	3%	0%	16%	3%	7%	18%	7%	21%	26%
Romania	11%	1%	23%	3%	7%	12%	11%	14%	14%
Russia	5%	10%	18%	3%	6%	21%	10%	14%	13%
Saudi Arabia	3%	46%	10%	1%	5%	6%	3%	9%	17%
Singapore	0%	0%	27%	2%	4%	17%	13%	23%	11%
Slovakia	4%	1%	20%	5%	6%	16%	11%	21%	17%
Slovenia	3%	1%	25%	3%	6%	14%	8%	21%	21%
South Africa	3%	7%	19%	2%	2%	14%	10%	21%	21%
Spain	3%	0%	16%	2%	11%	18%	7%	21%	20%
Sweden	2%	0%	20%	3%	5%	12%	8%	24%	26%

Country	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Switzerland	1%	0%	19%	2%	6%	16%	6%	20%	28%
Taiwan	2%	0%	22%	2%	2%	21%	7%	20%	12%
Thailand	12%	3%	34%	3%	3%	17%	8%	6%	11%
Tunisia	12%	5%	19%	2%	6%	17%	11%	13%	15%
Turkey	11%	1%	22%	3%	4%	22%	16%	10%	11%
Turkmenistan	24%	0%	34%	0%	8%	5%	6%	1%	3%
Ukraine	11%	5%	20%	4%	4%	13%	13%	8%	9%
UAE	2%	35%	13%	2%	7%	13%	7%	12%	9%
United Kingdom	1%	2%	13%	2%	6%	14%	7%	32%	22%
USA	1%	2%	12%	2%	5%	13%	3%	21%	41%
Venezuela	4%	30%	11%	2%	3%	12%	8%	12%	19%
Vietnam	21%	10%	21%	4%	6%	17%	4%	6%	11%

Table 8: Coefficients of Variance of Weather Variables

Country	**CV**$_{CDD}$	**CV**$_{HDD}$	**CV**$_{Precip}$
Argentina	0.16	0.13	0.40
Australia	0.19	0.33	0.50
Austria	0.69	0.06	0.16
Azerbaijan	0.18	0.06	0.31
Belarus	0.59	0.08	0.21
Belgium	0.59	0.08	0.23
Bolivia	0.29	0.38	0.34
Brazil	0.06	3.40	0.47
Bulgaria	0.52	0.06	0.30
Canada	1.05	0.08	0.51
Chile	0.56	0.10	1.12
China	0.36	0.09	0.30
Colombia	0.27	0.63	0.34
Croatia	0.25	0.07	0.22
Cyprus	0.10	0.13	0.24
Czech Republic	0.55	0.06	0.18
Denmark	0.84	0.08	0.35
Ecuador	0.53	2.70	0.29
Egypt	0.06	0.23	1.55
Estonia	0.65	0.08	0.20
Finland	0.94	0.07	0.24
France	0.45	0.08	0.25

Country	**CV**$_{CDD}$	**CV**$_{HDD}$	**CV**$_{Precip}$
Germany	0.08	0.47	0.16
Greece	0.15	0.08	0.40
Hungary	0.31	0.07	0.28
India	0.04	0.86	0.33
Indonesia	0.23	1.16	0.42
Ireland	1.31	0.06	0.18
Israel	0.13	0.20	0.57
Italy	0.33	0.09	0.51
Japan	0.14	0.13	0.24
Jordan	0.13	0.11	0.80
Kazakhstan	0.20	0.08	0.67
Kuwait	0.91	0.08	0.22
Latvia	0.62	0.08	0.18
Lithuania	0.37	0.05	0.21
Malaysia	0.04	0.06	0.66
Mexico	0.11	1.01	0.97
Morocco	0.19	0.15	0.40
Netherlands	0.52	0.07	0.21
New Zealand	0.70	0.38	0.49
Norway	1.33	0.05	0.19
Pakistan	0.08	0.00	0.25
Peru	0.27	0.93	1.05
Philippines	0.14	1.01	0.36

Country	**CV**$_{CDD}$	**CV**$_{HDD}$	**CV**$_{Precip}$
Poland	0.52	0.10	0.33
Portugal	0.34	0.08	0.36
Romania	0.62	0.06	0.38
Russia	0.81	0.06	0.39
Saudi Arabia	0.13	0.46	1.53
Singapore	0.27	0.06	0.23
Slovakia	0.77	0.05	0.23
Slovenia	0.30	0.13	0.25
South Africa	0.26	0.17	0.22
Spain	0.37	0.13	0.29
Sweden	0.93	0.07	0.23
Switzerland	0.76	0.12	0.65
Taiwan	0.10	0.71	0.36
Thailand	0.06	2.49	0.26
Tunisia	0.14	0.11	0.71
Turkey	0.16	0.08	0.51
Turkmenistan	0.22	0.09	0.47
Ukraine	0.25	0..28	0.72
U.A.E.	0.09	1.83	0.45
UK	0.07	0.81	0.16
USA	0.08	0.13	0.21
Venezuela	0.07	0.10	0.53
Vietnam	0.49	0.11	0.31

Table 9: Corrections Data

Country	**Yield/Hectare Correction**	**Tourism Correction**
Argentina	1.078	0.977
Australia	2.317	1.031
Austria	0.664	1.02
Azerbaijan	1.496	0.931
Belarus	1.524	0.937
Belgium	0.455	0.951
Bolivia	2.131	0.989
Brazil	1.255	0.956
Bulgaria	1.200	1.062
Canada	1.381	0.952
Chile	0.708	0.947
China	0.771	1.191
Colombia	1.076	0.968
Croatia	0.804	1.317
Cyprus	2.138	1.225
Czech Republic	0.860	0.974
Denmark	0.650	0.964
Ecuador	1.553	0.968
Egypt	0.523	1.17
Estonia	1.767	1.01
Finland	1.193	0.947
France	0.561	0.997

Country	**Yield/Hectare Correction**	**Tourism Correction**
Germany	0.589	0.945
Greece	1.009	1.216
Hungary	0.831	0.984
India	1.635	0.951
Indonesia	0.914	0.974
Ireland	0.533	0.949
Israel	1.316	0.968
Italy	0.773	0.998
Japan	0.656	0.937
Jordan	2.960	1.133
Kazakhstan	3.668	0.948
Kuwait	1.620	0.924
Latvia	1.639	0.963
Lithuania	1.420	0.982
Malaysia	1.189	0.975
Mexico	1.298	0.97
Morocco	3.190	1.184
Netherlands	0.485	0.945
New Zealand	0.577	1.083
Norway	0.997	0.945
Pakistan	1.620	0.93
Peru	1.147	0.987
Philippines	1.338	0.963

Country	**Yield/Hectare Correction**	**Tourism Correction**
Poland	1.260	0.977
Portugal	1.424	1.068
Romania	1.263	0.945
Russia	2.060	0.943
Saudi Arabia	0.903	0.954
Singapore	1.000	1.091
Slovakia	0.962	0.952
Slovenia	0.732	1
South Africa	1.377	1.025
Spain	1.274	1.083
Sweden	0.831	0.96
Switzerland	0.633	0.981
Taiwan	1.000	0.92
Thailand	1.364	1.001
Tunisia	2.660	1.063
Turkey	1.643	1.097
Turkmenistan	1.359	0.92
Ukraine	1.533	1.024
UAE	0.742	0.945
United Kingdom	0.557	0.969
USA	0.630	0.998
Venezuela	1.173	0.931
Vietnam	0.856	0.92