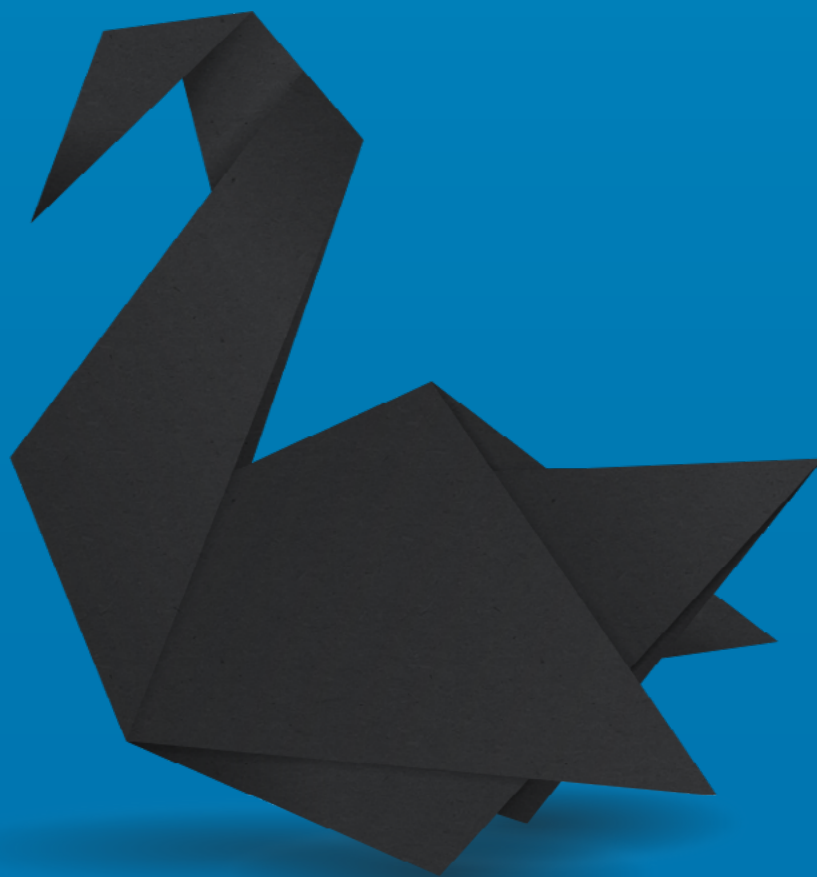


FROM KNOWN UNKNOWNNS TO BLACK SWANS

How to Manage Risk in Latin America and the Caribbean

Semiannual Report - Office of the Regional Chief Economist
October 2018



THE WORLD BANK

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Latin America & the Caribbean

**From Known Unknowns to Black Swans:
How to Manage Risk in Latin America and the Caribbean**

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ISBN (electronic): 978-1-4648-1373-3

DOI: 10.1596/978-1-4648-1373-3

Cover design: Javier Daza.

Acknowledgements

This report was prepared by a core team from the Office of the Chief Economist, Latin America and the Caribbean, composed of Carlos A. Végh (Regional Chief Economist), Guillermo Vuletin (Senior Economist), Daniel Riera-Crichton (Economist), Juan Pablo Medina (Consultant) and Diego Friedheim, Luis Morano, and Lucila Venturi (Research Analysts). The authors are particularly grateful to José Andrée Camarena for his superb research assistance. Members of the World Bank’s Regional Management Team for Latin America and the Caribbean asked numerous pointed questions and provided invaluable insights during a presentation that took place on September 13, 2018. Stefano Curto, the Acting Practice Manager of Macroeconomics, Trade, and Investment, and his team of country economists, particularly Cristina Savescu and Eduardo Olaberria, offered invaluable support. Daniel Angel, Jorge Araujo, Guillermo Beylis, María Ignacia Cuevas, María Marta Ferreyra, Andrea Franco, Luciana Galeano, Jesko Hentschel, Elena Ianchovichina, Samuel Pienknagura, Martin Raiser, Alberto Rodriguez, Pedro Rodriguez, Diego Rojas, Pablo Saavedra, Seynabou Sakho, Kinnon Scott, Joana Silva, Boris Weber, and Ulrich Zachau kindly provided insightful comments and suggestions. Peter Moll and Theo Thomas provided crucial information on World Bank operations. Alejandra Viveros (Manager, External Communications), Candyce Rocha (Senior Communications Manager), and Carlos Molina (Online Communications Officer) provided constant feedback and assistance that made this report more accessible to non-economists. Finally, this report would not have come to fruition without the unfailing administrative support of Ruth Eunice Flores and Jacqueline Larrabure.

October 2018

Executive Summary

After a six-year slowdown, which included a contraction in GDP of 1.0 percent in 2016, the Latin America and the Caribbean (LAC) region grew by 1.1 percent in 2017 and was expected, as late as this April, to grow at increasing rates in subsequent years. Unfortunately, in the last six months, the region has encountered some bumps in the road. Indeed, as analyzed in Chapter 1, (i) the macroeconomic crisis that started in April in Argentina, (ii) the growth slowdown in Brazil, (iii) the continued deterioration of the economic and social situation in Venezuela, and (iv) an external environment that has recently taken a turn for the worse have all conspired against the optimistic scenario of early this year and will result in lower growth in the region (now expected to be 0.6 percent in 2018). This reduction in growth will be mainly due to growth in South America coming to a screeching halt in 2018 (with GDP expected to remain essentially flat compared to a very modest, but yet positive, growth of 0.5 percent in 2017). In contrast, Central America and the Caribbean are expected to continue to grow at a healthy pace (2.8 and 3.7 percent, respectively, with growth in Central America being brought down by the political and economic crisis currently underway in Nicaragua). Mexico is expected to grow at 2.3 percent in 2018 (from 2.0 percent in 2017), a steady, if below potential, rate.

Three external factors remain relatively benign for the region: robust growth in the United States, a falling but still above 6 percent growth in China, and a recovery in commodity prices. The dark cloud in the horizon is clearly the normalization of monetary policy in the United States which, by increasing interest rates, has contributed to a drastic reversal in net capital inflows to the region, a strengthening of the dollar, and a fall in most major emerging markets' currencies. Indeed, net capital inflows to the region (measured as the 12-month cumulative figure), which peaked at 49.6 billion dollars in January 2018, have plummeted to 18.8 billion dollars in August. This dramatic fall has also been fueled by some nervousness in international bond markets regarding, in particular, the situation of Argentina, Turkey, and South Africa. In spite of projected growth of 1.6 percent for the region in 2019, in which case the slow 2018 growth will have proved to be a bump in the road, the overall situation still looks worrisome, with considerable political uncertainty in Brazil, a likely deepening of the current recession in Argentina, doubts about the sustainability of some key reforms in Mexico, a still unfinished renegotiation of NAFTA among its three founding members, and trade wars erupting with alarming frequency.

To compound the problems of some of the major economies in the region and an international environment turning bleaker, the region's poor fiscal situation barely improved over last year, with 29 out of 32 countries projected to show a negative overall fiscal balance in 2018 (Chapter 1). As a result, external public debt has surpassed 60 percent of GDP for the region as a whole, with six countries having debt ratios above 80 percent. These high debt levels continue to weaken credit ratings (since January 2017, Fitch has downgraded the credit rating of seven LAC countries, including Brazil and Chile), which has increased the risk premium paid by non-investment LAC countries (excluding Venezuela) to 356 basis points. Hence, access and cost of international credit are, once again, becoming more challenging when most needed. Higher debt also reduces fiscal space and severely curtails the possibility of using fiscal policy as a countercyclical policy tool, precisely at a time when many central banks in the region feel the need to raise policy rates to defend the

domestic currency or, at least, ensure an “orderly depreciation.” The region has no choice but to increase the pace of fiscal adjustment to ensure debt sustainability in the short and medium run, especially if net capital inflows to the region continue to fall. To the extent possible, this fiscal adjustment should be undertaken while protecting public investment in infrastructure (vital for future growth prospects) and social programs (to preserve the considerable social gains achieved during the Golden Decade of high commodity prices).

The dramatic fall in net capital inflows to the region (or “sudden stop”) brings once again to the fore the risks faced by LAC. In addition to economic risks, natural disasters (such as earthquakes, hurricanes, and droughts, among others) bring devastation with disturbing frequency. There is thus no doubt that, as shown in the report, we live in a highly risky region. The good news, as explored in the core of the report (Chapters 2, 3, and 4), is that our understanding of the risks faced by the region has enabled us to manage them much better than in the past, both ex-ante (through various insurance and precautionary instruments) and ex-post (with readily-available aid).

Chapter 2 lays the foundations for the analysis of risk in the region. It shows how critical it is to understand the nature of the risks faced by the region to infer what is the best kind of response. We divide risks into “known unknowns” and “unknown unknowns.” The idea behind these terms is, in fact, very simple. Known unknowns are risks (like rain in many countries) for which we know the stochastic distribution that they follow (i.e., we can compute with a high degree of accuracy the probability of different amounts of rain falling based on decades of statistics) and hence we can easily insure against. Think about a car insurance company. While the company may not know what person, in particular, will have an accident in 2019, it does know with very high precision (because it insures millions of drivers) how many accidents there will be in total and how much it will have to pay in insurance claims. So, effectively, the risk faced by the car insurance company is almost non-existent. At the other extreme, unknown unknowns (or black swans) are events that cannot be predicted because they have never occurred before and therefore we have no idea of what is the probability that they will take place. As a result, we cannot insure. A good example is 9/11. Nobody could have predicted on 9/10 that 9/11 would happen. Since insurance is not available, society has no choice but to rely on improving its resilience and general readiness and as much aid as possible after the fact.

The good news, as analyzed in Chapter 3, is that we have made tremendous advances in our ability to insure against risks. Even risks that have “fat tails” (i.e., very large events, like earthquakes, which are rare but can certainly happen and cause widespread loss of life and economic damage) can be insured against as long as tails are not too fat and insurers can somehow protect against them. An excellent example, which will undoubtedly revolutionize sovereign insurance in this area, is the Pacific Alliance Catastrophe Bond against earthquakes signed in February 2018, with active participation of the World Bank. Risk is transferred to the financial markets by selling catastrophe bonds (whose proceeds are deposited in special purpose vehicles) that, in case of an earthquake in any of the four member countries (Chile, Colombia, México, and Perú) will be paid to that country. If an earthquake does not happen during the term of the bond, investors are given the proceeds of the bonds plus the corresponding interest. The fact that the correlation between earthquakes in different countries is very low greatly reduces the risk borne by investors and hence lowers the price of insurance.

Hurricanes in the Caribbean are, at this point, more difficult to insure against because they tend to cause widespread damage in many island nations at the same time (i.e., damage in different countries may be highly correlated), which implies that ex-post aid continues to be the main risk management instrument. Having said that, risk sharing across countries through mechanisms such as the Caribbean Catastrophe Risk Insurance Facility (CCRIF) can certainly provide readily-available funds in case of a member country facing a hurricane.

In sum, the general proposition that emerges from our analysis is that the fatter the tails of the distribution (i.e., the more likely the occurrence of rare and large events), the less market insurance will be available, and the more ex-post aid will be needed (Chapter 4). But far from standing still, our understanding of the characteristics of different risks continuously evolves, both from a theoretical and practical point of view. Catastrophe bonds for earthquakes would have been unthinkable some time ago and there is no doubt that, in a not too distant future, the region will be able to insure against many more risks, thus making LAC a much safer place to live and prosper.

Chapter 1:

Growth and Fiscal Challenges in the Region

Introduction

After six years of growth deceleration (including negative growth in 2016), the Latin America and the Caribbean (LAC) region had firmly, if modestly, turned the page in 2017 and had grown by 1.1 percent (Table 1.1 and Figure 1.1, Panel A). A pickup in commodity prices, abundant net capital inflows to the region, a rather gradual pace of monetary policy normalization in the advanced economies – particularly the United States – and the economic recoveries in Argentina and Brazil had all contributed to this turnaround and the widespread expectation that the region had finally resumed a path of increasing growth.

TABLE 1.1. Recent and Forecasted Real GDP Growth in LAC

Region	Annual Real GDP Growth Rates (as percentage)				
	2015	2016	2017	2018f	2019f
LAC	0.2	-1.0	1.1	0.6	1.6
LAC (excl. Venezuela, RB)	0.5	-0.2	1.8	1.6	2.1
Central America	4.2	3.8	3.7	2.8	3.2
Caribbean	3.9	2.9	2.4	3.7	3.5
Mexico	3.3	2.9	2.0	2.3	2.3
South America	-1.1	-2.6	0.5	-0.1	1.2
South America (excl. Venezuela, RB)	-0.8	-1.6	1.6	1.2	1.9
Argentina	2.7	-1.8	2.9	-2.5	-1.6
Brazil	-3.5	-3.5	1.0	1.2	2.2
Colombia	3.0	2.0	1.8	2.7	3.3
Venezuela, RB	-6.2	-16.5	-14.5	-18.2	-8.4

Notes: Sub-regional values are weighted averages; “f” stands for forecast. South America includes Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, and Venezuela, RB. Central America includes Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama. Caribbean includes Antigua and Barbuda, The Bahamas, Barbados, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, and Trinidad and Tobago. Sources: World Bank staff estimates (September 2018) when available, otherwise WEO (April 2018).

Over the last six months, unfortunately, some stumbling blocks have suddenly showed up in the recovery road. Argentina’s efforts to transform its economy, while confronting the challenge of unwinding macroeconomic imbalances and mitigating the social costs of transition, took a somewhat unexpected turn of events when, on May 8th, Argentina announced that it would approach the

International Monetary Fund (IMF) seeking considerable financial support to ensure payment of its external obligations over the next three years. On June 7th, the IMF announced that it had reached a stand-by arrangement with the Argentinean authorities on a 36-month program for 50 billion dollars. Not surprisingly, the cornerstone of the agreement was to accelerate the pace of the fiscal adjustment and redouble efforts to lower inflation.¹

Despite the unprecedented level of support, turmoil in currency markets continued, with the price of the dollar surpassing 40 pesos on August 30th (from 17.6 pesos at the end of April), which forced the central bank to raise policy rates to unheard-of levels of 60 percent to defend the currency. As expected, the acceleration of the fiscal adjustment and the level of interest rates needed to defend the peso are already taking a toll on the economy, which is expected to contract by 2.5 percent in 2018 (compared to a forecast of 2.7 percent growth in April 2018).^{2 3} Furthermore, in a turn for the worse, on August 29th President Macri announced that Argentina would seek to renegotiate the IMF agreement in order to accelerate disbursements so that external payments in 2019 would be assured even without market support, in exchange for bringing forward the fiscal adjustment originally agreed (and achieving fiscal balance already in 2019). A re-negotiation between the IMF and the Argentinean authorities over 57.1 billion dollars (an increase of 7.1 billion dollars) was announced on September 26, 2018.

Brazil, which accounts for more than a third of the region's GDP, is expected to fare better than neighboring Argentina but still considerably below earlier forecasts. At the end of June, the central bank slashed its 2018 growth estimate to 1.6 percent (down from 2.6 percent) after a nationwide truckers' strike paralyzed large sectors of the economy. The persistence of large and seemingly intractable fiscal deficits, lack of meaningful pension reform, and growing political uncertainty regarding the October elections, in conjunction with recent apprehension in international capital markets, have brought into question even such modest growth, with the current forecast being 1.2 percent for 2018 (Table 1.1 and Figure 1.1, Panel B).

To make matters worse, Venezuela continues to implode with an economic, financial, and social crisis unprecedented in the modern history of the region. Venezuela's GDP is expected to fall by 18.2 percent in 2018, with a cumulative fall of more than half during the last 5 years. Inflation is expected to reach an annual rate of 1,000,000 percent by the end of the year. According to the UN's International Organization for Migration, more than 1.6 million people have left Venezuela since 2015, straining social and housing resources in neighboring countries, particularly Colombia that is hosting an estimated 935,000 Venezuelans migrants.

¹ For details on the IMF's stand-by arrangement with Argentina, see Press Release No. 18/216 on the IMF's website.

² See Végh *et al.* (2017b) for a detailed analysis of the output costs of having to defend the currency in times of financial turmoil and the monetary policy dilemma faced by emerging markets in such an environment.

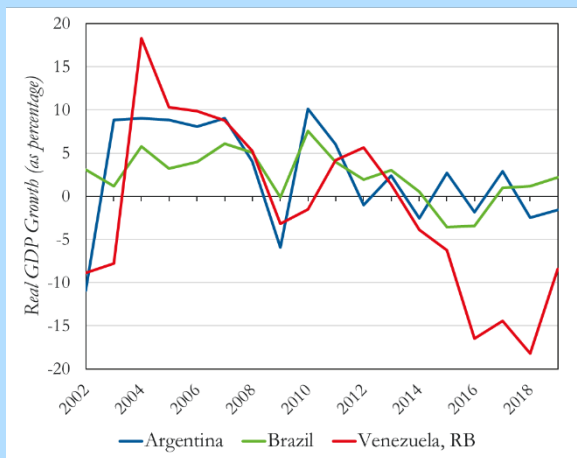
³ See Table A.1 (Appendix A) for the growth figures of all 32 LAC countries.

FIGURE 1.1. LAC: Real GDP Growth

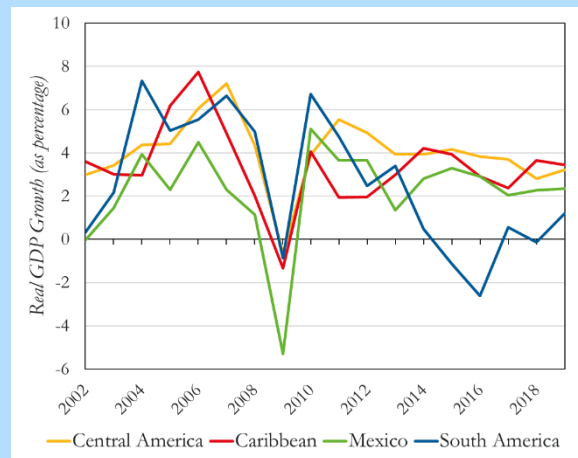
PANEL A. LAC



PANEL B. Selected SA Countries



PANEL C. Sub-Regions

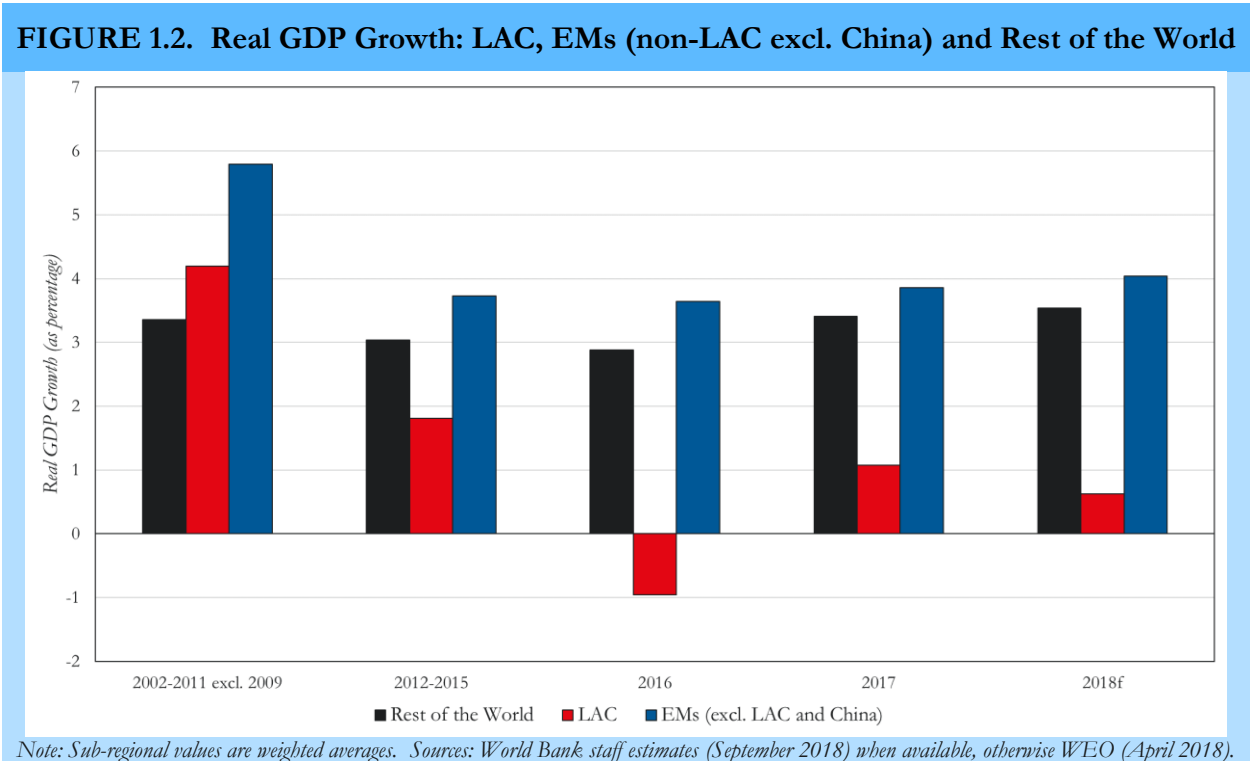


Notes: Sub-regional values are weighted averages. Growth figures for 2018 and 2019 are forecasts. South America includes Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, and Venezuela, RB. Central America includes Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama. Caribbean includes Antigua and Barbuda, The Bahamas, Barbados, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, and Trinidad and Tobago. Sources: World Bank staff estimates (September 2018) when available, otherwise WEO (April 2018).

In sum, GDP in South America (SA) is expected to remain essentially flat in 2018 and grow by 1.2 percent in 2019 (Table 1.1 and Figure 1.1, Panel C). In this light, and since SA accounts for more than 70 percent of the region’s output, we estimate LAC to grow by 0.6 percent in the year 2018

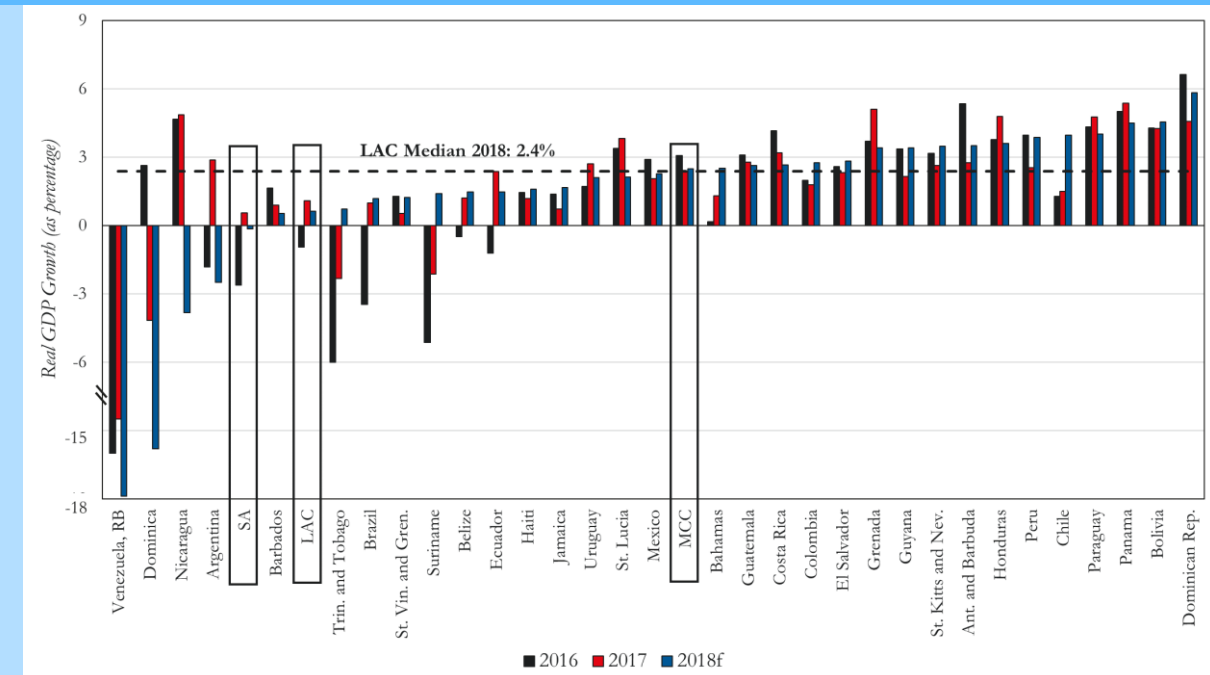
(compared to growth of 1.1 percent in 2017) and by 1.6 percent in 2019.⁴ As always, the region’s overall growth masks a large degree of heterogeneity across sub-regions (Figure 1.1, Panel C). Central America (CA) is expected to grow by 2.8 percent (down from 3.7 percent in 2017, partly reflecting the political and economic crisis in Nicaragua), the Caribbean by 3.7 percent, and Mexico by 2.3 percent.⁵ The Caribbean has resumed healthy growth after the devastation caused by hurricanes Irma and Maria in 2017. CA has benefited from fairly robust growth in the United States despite lingering uncertainty regarding immigration and trade. Mexico, on the other hand, continues to underperform relative to expectations, though the prolonged and difficult negotiations regarding NAFTA, the political uncertainty associated with the recent elections, and whether current policies will remain in place have undoubtedly affected growth prospects, at least in the short run.

Figure 1.2 shows LAC’s GDP growth compared with that of Emerging Markets (excluding China) and the Rest of the World. For the last six years, the region has lagged behind relative to the Rest of the World. Although most of the economies in the world have shown slower growth after 2011 compared with the period 2002-2011 (excluding 2009), the deceleration in LAC has been particularly strong. In fact, as Figure 1.2 makes clear, the region has consistently underperformed relative to the two other groups since 2012. The only time span during which the region outperformed the Rest of the World was the commodity boom episode, as captured by the period 2002-2011 in Figure 1.2.



⁴ Excluding Venezuela, GDP growth in LAC is expected to be 1.6 percent in 2018 and 2.1 percent in 2019.

⁵ Nicaragua’s GDP is expected to fall by 3.8 percent in 2018, down from positive growth of 4.9 percent in 2017. Even though Nicaragua’s GDP is only 5.3 percent of that of Central America, such a large fall in GDP subtracts 0.4 percentage points from Central America’s growth in 2018.

FIGURE 1.3. Real GDP Growth in LAC per Country, 2016-2018


Notes: Sub-regional values are weighted averages. SA includes Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Suriname, Uruguay, and Venezuela, RB. MCC includes Antigua and Barbuda, The Bahamas, Barbados, Belize, Costa Rica, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, and Trinidad and Tobago. Sources: World Bank staff estimates (September 2018) when available, otherwise WEO (April 2018).

In terms of individual countries, Figure 1.3 shows the growth rate in 2016, 2017, and the forecast for 2018 for all countries in LAC. Two of the five fastest growing economies in 2018 are expected to be from the Caribbean and Central America (Dominican Republic and Panama) and three from SA (Bolivia, Paraguay, and Chile). The median rate of real GDP growth for all countries in 2018 is expected to be 2.4 percent, with the mean for LAC, SA, and MCC being, respectively, 0.6, -0.1, and 2.5 percent.⁶ Hence, once again, we see the pattern of MCC doing better in terms of growth than SA.

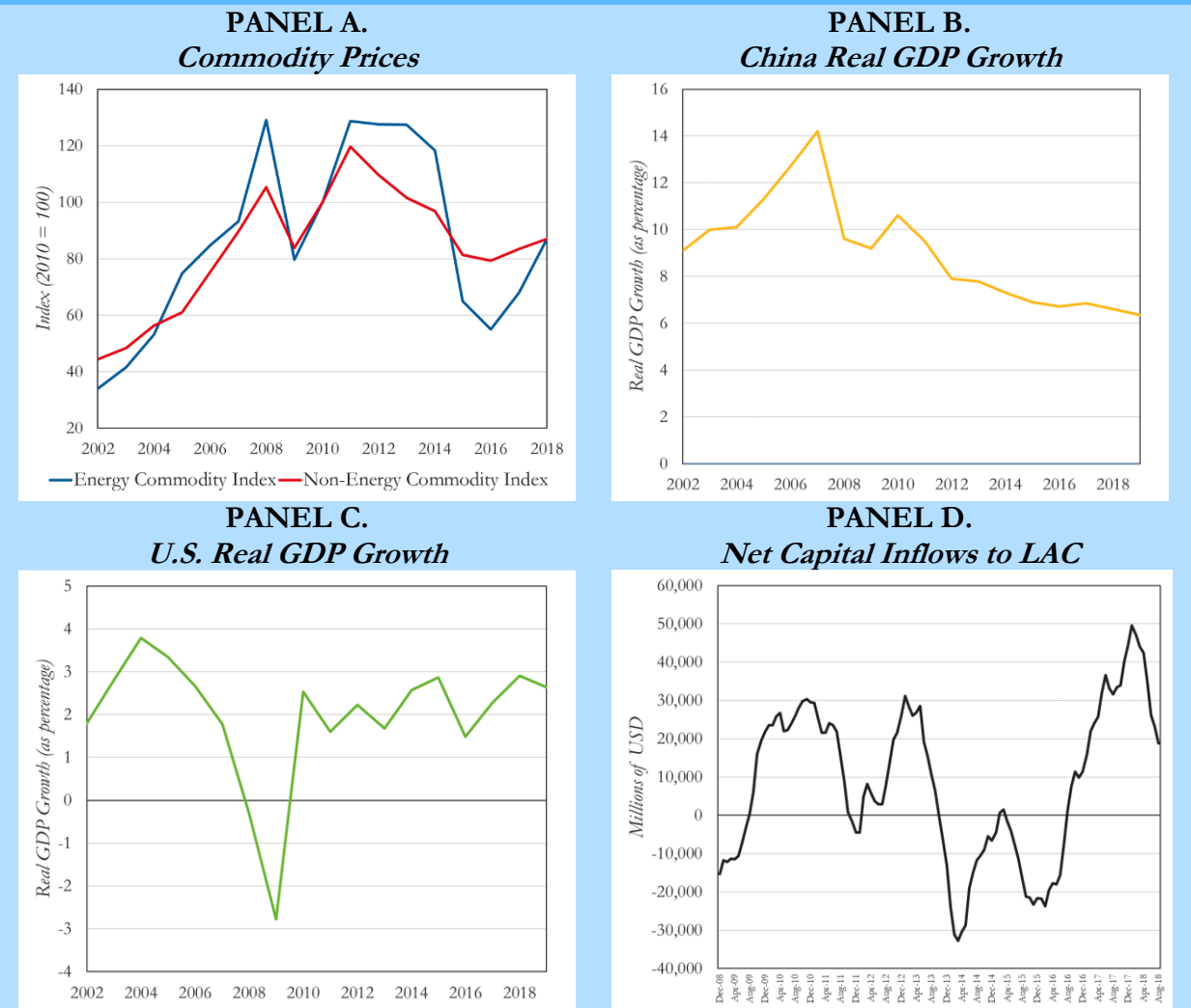
Given the significant difference in growth across sub-regions of LAC, it is natural to ask what factors may explain this phenomenon: external or domestic? The next section tackles this question.

Bumps in the Road and the Role of External Factors

For small open economies, as those in LAC, external factors play a fundamental role in determining growth. In fact, external factors have been a critical determinant of the marked deceleration in growth experienced by SA since 2011. Typically, commodity prices, growth in China and the U.S., and international liquidity – as captured, for instance, by net capital inflows to the region – are among the most important external factors. Figure 1.4 illustrates the recent path of these four factors.

⁶ MCC stands for Mexico, Central America, and the Caribbean.

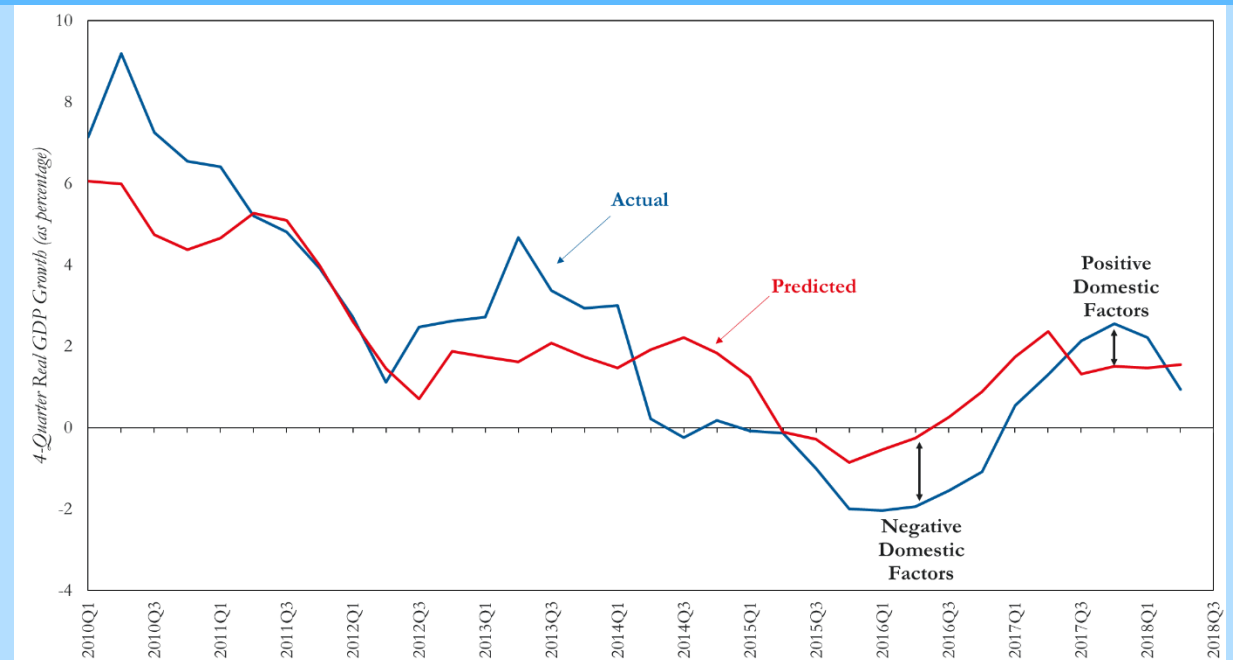
FIGURE 1.4. External Factors Affecting LAC Growth



Note: Forecasts for 2018 were included when available. Sources: EPFR Global, Haver Analytics, and World Bank Commodity Price Data (Pinksheets).

Commodity prices have recovered from their lows in 2016, particularly those of energy. This is especially the case of the price of oil, which more than doubled from 30.8 dollars per barrel in January 2016 to a high of 76.7 dollars per barrel in May 2018. China’s growth has slowed down but continues to be robust as is growth in the United States. Net capital inflows, however, have plummeted so far in 2018 – after a very strong 2017 – reflecting, as discussed above, the negative sentiment towards emerging markets resulting from the fragile macroeconomic situations in, especially, Argentina and Turkey and the firming up of interest rates in the United States.

To shed light on the quantitative importance of external factors in determining growth in SA, we use the WIM model as in previous issues of this report. The model estimates the effects of four external variables on the growth rate of each country in LAC (see De La Torre *et al.*, 2013). In line with the above discussion, the explanatory variables are the growth rates of the G-7 and China, an index of commodity prices, and the United States 10-year Treasury real yield as a proxy for the global cost of capital.

FIGURE 1.5. Role of External Factors in South America’s Growth


Notes: See text for details. Guyana, Suriname, and Venezuela, RB are not included. Sources: Authors’ estimations based on data from Bloomberg and Haver Analytics.

Figure 1.5 illustrates the results from the model. The blue line shows the actual growth rate of SA while the red line shows the growth rate predicted by the model. This predicted value summarizes the average effect of the external factors on the growth rate. Therefore, the difference between both lines can be interpreted as the influence of domestic factors (e.g., monetary and fiscal policy, and structural reforms). If the blue line lies above the red line, then positive domestic factors are raising growth above the level explained by external factors. Conversely, if the blue line lies below the red line, then negative domestic factors are reducing growth below the level explained by external factors.

The figure makes clear three important points. First, the sharp growth deceleration suffered by SA since 2011 was mainly due to external factors, as can be inferred from the fact that the red line falls rather steadily from 2010 onwards. Second, during 2015 and 2016, various factors (in particular, the recession in Brazil) negatively affected SA, which explains that actual growth is below that explained by external factors. As of 2018:Q2, actual growth of 0.9 percent is below the one predicted by external factors (1.5 percent). This reflects the poor performance of the major South American economies, as discussed above. As already emphasized in this series of reports, SA will need to generate its own sources of growth since, at this time, it cannot rely exclusively on external factors that, overall, continue to provide a gentle push at best. Countries thus need to push on with much-needed reforms, particularly in the areas of infrastructure, social security, labor markets, and deregulation.

By their very nature, external factors are volatile and cannot be relied upon to generate steady growth. In particular, commodity prices and capital inflows fluctuate considerably, exposing South America to the vagaries of the commodity price cycle (in turn, greatly influenced by China’s business cycle and the corresponding demand for commodities) and the capital flows cycle (which responds to monetary

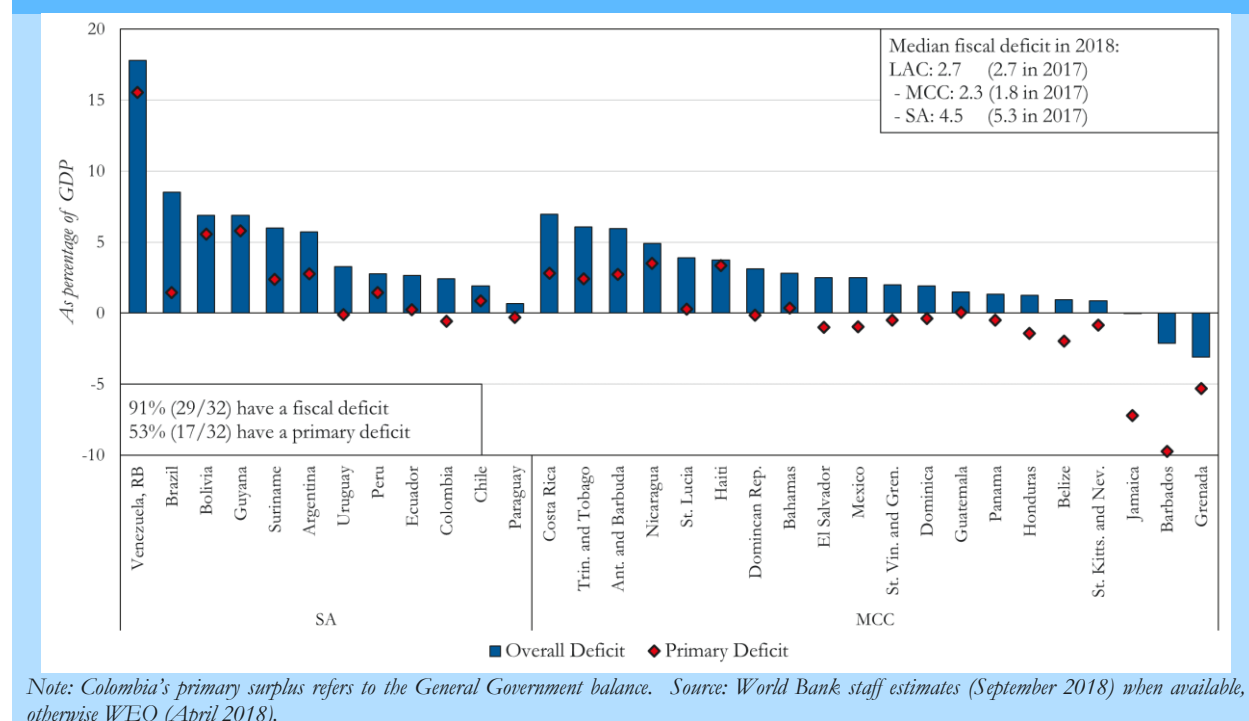
policy in the United States and international investors' risk appetite, among other factors). This inherent volatility imposes risks to the region, which will be analyzed in detail in later chapters of this report, and raises the critical question of how the region can protect itself against these risks. The importance of how to manage risk, through various insurance mechanisms, also applies to natural disasters such as earthquakes and hurricanes, which have a major impact on the economic and social well-being of the region.

Fiscal Adjustment in LAC: A Progress Report

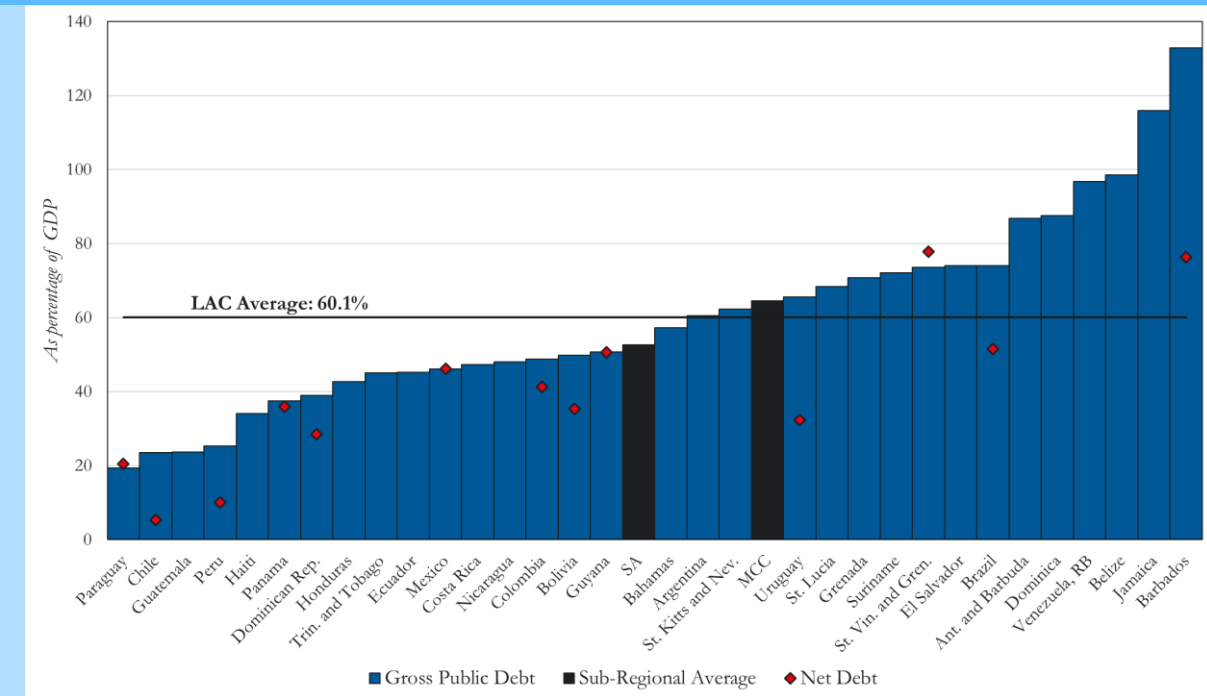
The fiscal situation of most countries in the region continues to be weak, as reflected in the fact that 29 out of 32 countries are expected to have an overall fiscal deficit in 2018 (Figure 1.6).⁷ The median fiscal deficit for LAC is 2.7 percent of GDP, with that of SA (4.5 percent) almost twice as much as that of MCC (2.3 percent). If there is a silver lining, it is the fact that many MCC countries (including Mexico) show a primary surplus, a rare fact among SA countries. Indeed, only three South American countries (Colombia, Paraguay, and Uruguay), are expected to have a primary surplus in 2018.

Not surprisingly, the deterioration of fiscal deficits has been reflected in high levels of public debt (as of end of 2017), as illustrated in Figure 1.7. The average level of gross debt for the region is now 60.1 percent of GDP, with six countries (Barbados, Jamaica, Belize, Venezuela, Dominica, and Antigua and Barbuda) surpassing 80 percent of GDP.

FIGURE 1.6. Fiscal Deficits in LAC, 2018



⁷ See previous reports in this series (Végh *et al.*, 2017a, 2018) for a detailed analysis of how the region got into this dire fiscal situation and the needed fiscal adjustments to ensure long-run debt sustainability.

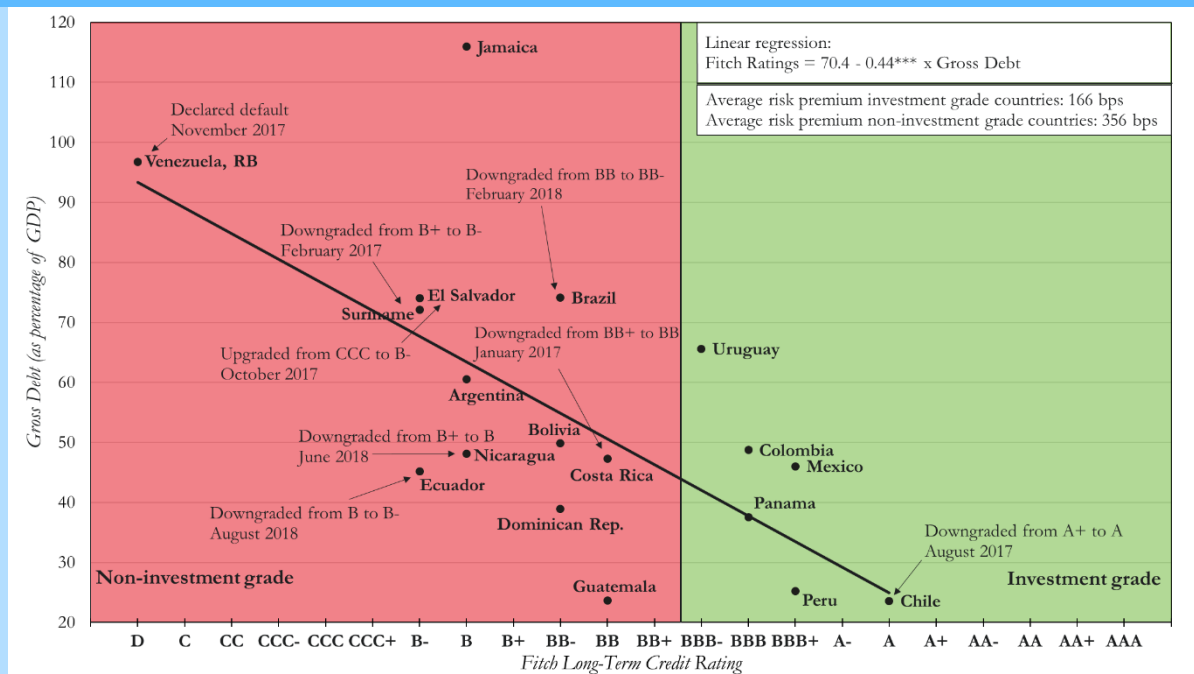
FIGURE 1.7. Gross and Net Debt in LAC, 2017


Sources: World Bank staff estimates (September 2018) when available, otherwise WEO (April 2018).

Higher levels of deficits/public debt eventually have a negative impact on international credit ratings. Indeed, Figure 1.8 shows a significant negative relation between higher debt levels and credit ratings, implying that markets view higher debt levels as affecting countries’ repayment capacity. So far in 2018 there have been three downgrades (Brazil, Nicaragua, and Ecuador). In total, during 2017 and the first eight months of 2018, Fitch made eight changes of which seven were downgrades (including major regional players, such as Brazil and Chile) and only one was an upgrade. Worse credit ratings have, of course, a direct negative financial impact as they increase the cost of rolling over existing debt or issuing new debt.

Given the weak fiscal situation in SA, there is little doubt that countries will need to step up fiscal adjustments in the near future. Figure 1.9, however, shows that fiscal adjustments are proceeding quite slowly throughout the region. While gradual fiscal adjustments are less costly than shock adjustments (Végh *et al.*, 2018) and should hence be the preferred choice of policymakers, lack of fiscal adjustment is an entirely different matter. This is best exemplified by the case of Argentina (Panel A), where the government efforts to reduce public spending in 2016 and 2017 did not translate into an overall improvement of the fiscal situation because of the impact of high inflation and exchange depreciation on public pensions, the wage bill and debt service, and tax reforms that entailed a revenue cost. The result has been that, as soon as the external environment turned harsher, markets’ concerns about debt sustainability forced Argentina to approach the IMF, as already discussed. In SA, in fact, except for Ecuador, there has been little fiscal adjustment. The same is true of Central America, except for Panama, and Dominican Republic (Panel B).

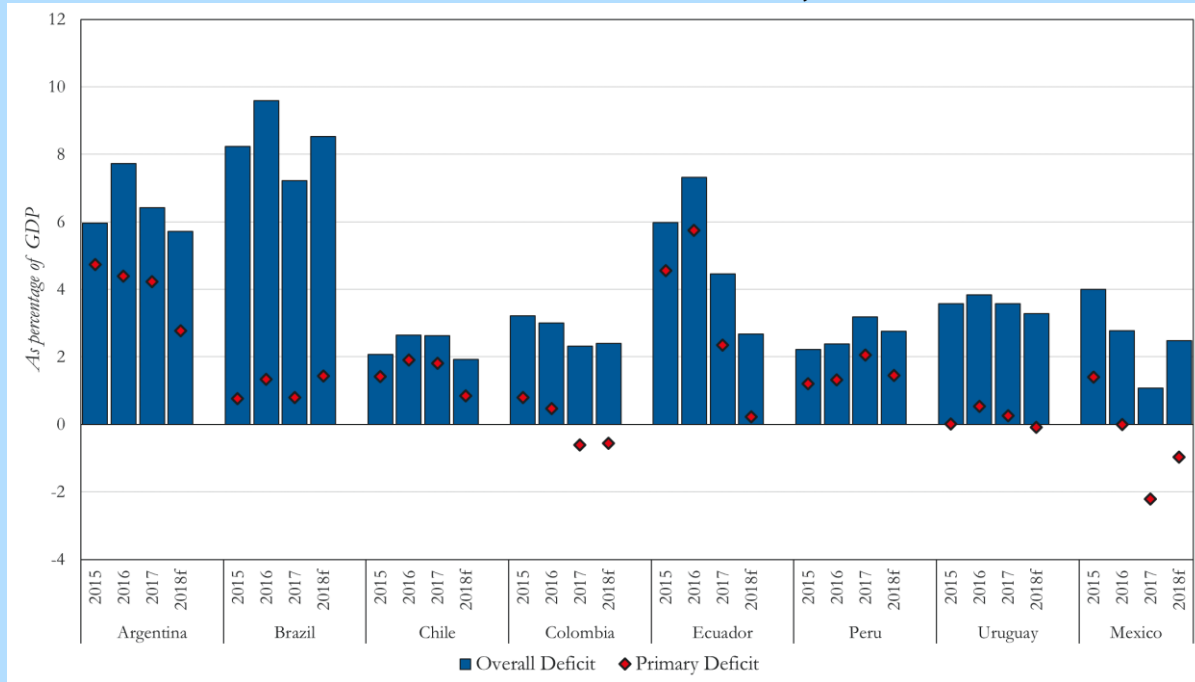
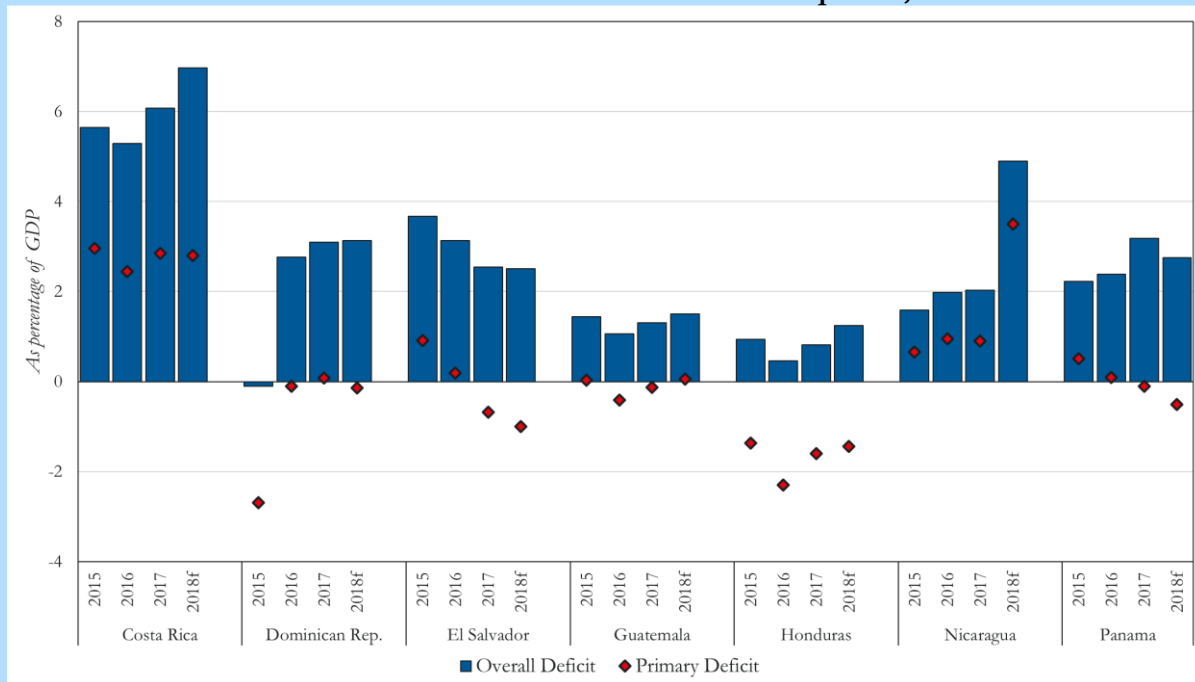
FIGURE 1.8. Debt and Credit Ratings in LAC, 2017



Note: Venezuela, RB is not included in the calculation of the average risk premium for non-investment grade countries. Sources: World Bank staff estimates (September 2018) and Fitch Ratings.

Unfortunately, these much-needed fiscal adjustments will need to be conducted in the context of downside risks. In particular, and as already mentioned, external factors such as the normalization of monetary policy in the U.S. – which pulls capital out of the region, strengthens the dollar, and weakens domestic currencies – the still uncertain outcome of NAFTA renegotiations, and trade wars in the context of protectionist tendencies in the U.S. will weigh heavily on the region. Domestic factors will not help either, with political and economic uncertainty in Brazil and, particularly, Argentina (which will be holding presidential elections in October 2019), and the crisis in Venezuela and its effects on neighboring countries.

But risks are a fact of life, particularly in our region. Both economic risks (such as sudden capital flow reversals and fluctuations in commodity prices) and natural disasters (such as earthquakes and hurricanes) are always in the minds of policymakers and multilateral organizations such as the IMF, World Bank, the Inter-American Development Bank (IDB), and the *Corporación Andina de Fomento* (CAF). The good news is that, by a thorough understanding of the types of risk faced by the region, we can develop highly sophisticated insurance arrangements. In case this is not possible (because risks are very hard to assess ex-ante), quick and readily-available ex-post aid is an effective answer, along with different measures to improve resilience and countries’ ability to strongly respond to the shock. The following chapters, which constitute the core of the report, offer a detailed analysis of different risks faced by the region and how to best manage them.

FIGURE 1.9. Fiscal Deficits in Selected LAC Countries
PANEL A. South America and Mexico, 2015-2018

PANEL B. Central America and Dominican Republic, 2015-2018


Note: "f" stands for forecast. Source: World Bank staff estimates (September 2018).

Chapter 2:

Fundamentals of Risk

Introduction

By now, it has become commonplace for the leading financial press, policy reports, and senior officials from multilateral organizations to warn the public about Latin America and the Caribbean having to face “growing [political and economic] uncertainties,” or “downside risks to [growth] prospects over the medium term,” or “risks and uncertainties clouding the horizon of the global economy.”⁸ These articles focus on both political and institutional uncertainty and external economic risks, such as falling commodity prices, growing cost of foreign debt, and slowing external demand from major trading partners. Combined with the tremendous challenges related to dealing with the aftermath of the devastating natural disasters that plagued the region, such gloomy scenarios seem to confirm the traditionally-held view by academics and practitioners that LAC is a risky place.

Living with imperfect knowledge of the future presents many challenges for emerging markets, including the potential inability to effectively protect the country against negative shocks (or take full advantage of positive ones).⁹ Given these challenges, it is worth starting this chapter by evaluating LAC’s exposure to risk. We will then take a step back and think more carefully about the critical distinction between risk and uncertainty (or, in modern lingo, “known unknowns” and “unknown unknowns”). In particular, we will take a look at different distributions (which tell us the properties of random variables) and analyze the fundamental idea that while we can certainly insure against some risks, there is little we can do against others (like “black swans”). A proper understanding of the relationship between different types of risk and the ability to insure is critical for managing risk in modern economies. Finally, we will discuss the region’s vulnerability to various risks.

How Risky is the Region?

Given that this is a rather complex question to answer, we will provide a first pass by, as is often done, proxying risk by real output volatility. Although a crude approximation at best, it provides a natural starting point for our analysis of risk.

⁸ See *The Economist* (2017), IMF (2018a, p.17), *Financial Times* (2018), and Furusawa (2018, p.2).

⁹ See, for example, World Bank (2013) and Baez *et al.* (2017).

TABLE 2.1. Volatility across Regions, 1960-2017

Region	Advanced Economies	Emerging Asia	Emerging Europe	Latin America and the Caribbean	Middle East and North Africa	Sub-Saharan Africa
<i>Output volatility</i>						
Real GDP per capita growth	2.6 (1.0)	4.1 (3.3)	4.6 (2.5)	4.2 (1.2)	7.2 (6.1)	5.2 (3.4)
<i>Sources of shock volatility</i>						
Terms of trade growth	2.8 (2.6)	6.3 (4.8)	3.6 (3.8)	9.6 (4.4)	9.8 (8.9)	10.4 (6.9)
Main trading partners' growth	0.9 (0.2)	1.3 (0.5)	1.1 (0.6)	1.1 (0.4)	1.3 (0.5)	1.1 (0.7)
Private gross capital inflows/Potential GDP	1.8 (1.9)	2.6 (4.1)	2.1 (1.3)	2.6 (5.9)	2.5 (4.4)	2.1 (4.6)
Spread (in basic points)	70.5 (193.8)	284.1 (138.6)	264.3 (228.9)	365.1 (362.9)	393.7 (130.6)	501.3 (365.4)
Yield (in percentage)	1.6 (1.3)	1.6 (0.9)	1.7 (1.7)	2.0 (3.0)	2.0 (0.9)	2.3 (2.9)
All natural disasters	44.9 (6.3)	76.7 (5.0)	14.5 (1.0)	40.5 (1.2)	21.4 (1.3)	38.8 (0.6)
Earthquakes	2.9 (0.2)	6.8 (1.0)	2.1 (0.4)	3.4 (0.2)	3.8 (0.7)	0.7 (0.0)
Floods	11.2 (1.1)	26.2 (1.7)	5.5 (0.3)	15.3 (0.6)	9.8 (0.5)	13.6 (0.3)
Storms	21.4 (4.3)	26.2 (2.0)	1.8 (0.1)	10.4 (0.5)	1.9 (0.1)	4.0 (0.3)
World Risk Index	3.3	9.8	4.6	7.2	5.8	8.2

Notes: See Appendix B for countries included in each region. The reported volatilities correspond to the standard deviation for the growth rates (as percentage) for GDP, terms of trade, and main trading partners' growth. Private gross capital inflows are the aggregation of all debit entries against all credit entries of liabilities in portfolio investments and other investments of the private sector; the figure reported is the coefficient of variation (expressed as percentage). The spread and yield correspond to the median of the average and the standard deviation across countries, respectively. Natural disasters correspond to the frequency of occurrence (average disasters per year). For each region, the entries for all variables correspond to the median value across countries, except for the disaster variables that correspond to the mean across countries. The World Risk Index is the average risk index between 2012 and 2016. The index is based on 28 individual indicators and rates disaster risk for 171 countries due to five natural hazards: earthquakes, cyclones, floods, droughts, and sea-level rise. The standard deviation of each measure across countries is reported between parentheses. Sources: Bloomberg, BOP-IMF, Bündnis Entwicklung Hilft, DOTS-IMF, EM-DAT, and WDI.

Following a large literature, the first lines in Tables 2.1 and 2.2 compute the real GDP per capita growth volatility across the main regions in the world (Table 2.1) and the main sub-regions of LAC (Table 2.2).¹⁰ The figures in Table 2.1 show that, over the last sixty years, real GDP per capita growth has been almost twice as volatile in LAC than in Advanced Economies (4.2 compared to 2.6 percent). Moreover, all LAC sub-regions have endured substantially larger output volatility than their industrialized counterparts, with the Caribbean the most volatile and Central America the least (Table 2.2). When comparing LAC's economies to other emerging markets, a silver lining emerges. Not only is the region's output volatility in line with other emerging regions such as Eastern Europe and

¹⁰ See, for example, Loayza *et al.* (2007), Raddatz (2008), and Barrot Araya *et al.* (2016).

Emerging Asia, but is actually smaller than developing countries in Sub-Saharan Africa and conflict-riddled economies in Middle East and North Africa (MENA). Silver linings aside, Table 2.1 is consistent with the view that LAC is a risky neighborhood and demands a deeper understanding of the fundamental risks faced by the region and how to best manage them.

TABLE 2.2. Volatility across Sub-Regions of LAC, 1960-2017

Sub-Region	Caribbean	Central America	South America and Mexico
<i>Output volatility</i>			
Real GDP per capita growth	4.5 (1.2)	3.7 (1.3)	4.2 (1.0)
<i>Sources of shock volatility</i>			
Terms of trade growth	6.8 (3.2)	14.2 (4.6)	10.6 (3.9)
Main trading partners' growth	1.2 (0.5)	1.1 (0.1)	1.1 (0.3)
Private gross capital inflows/Potential GDP	2.1 (8.4)	2.0 (3.7)	3.4 (2.5)
Spread (in basic points)	496.0 (103.5)	381.2 (193.6)	339.4 (455.3)
Yield (in percentage)	1.9 (1.0)	1.4 (1.2)	2.6 (3.6)
All natural disasters	9.3 (0.7)	8.0 (0.3)	23.2 (1.2)
Earthquakes	0.2 (0.0)	0.9 (0.1)	2.4 (0.2)
Floods	2.5 (0.4)	3.0 (0.1)	9.9 (0.7)
Storms	5.4 (0.2)	1.8 (0.1)	3.2 (0.7)
World Risk Index	7.0	14.8	6.2

Notes: The reported volatilities correspond to the standard deviation for the growth rates (as percentage) for GDP, terms of trade, and main trading partners' growth. Private gross capital inflows are the aggregation of all debit entries against all credit entries of liabilities in portfolio investments and other investments of the private sector; the figure reported is the coefficient of variation (expressed as percentage). The spread and yield correspond to the median of the average and the standard deviation across countries, respectively. Natural disasters correspond to the frequency of occurrence (average disasters per year). For each sub-region, the entries for all variables correspond to the median value across countries, except for the disaster variables that correspond to the mean across countries. The World Risk Index is the average risk index between 2012 and 2016. The index is based on 28 individual indicators and rates disaster risk for 171 countries due to five natural hazards: earthquakes, cyclones, floods, droughts, and sea-level rise. The standard deviation of each measure across countries is reported between parentheses. Sources: Bloomberg, BOP-IMF, Bündnis Entwicklung Hilft, DOTS-IMF, EM-DAT, and WDI.

Exposure and Vulnerability to External Risks: Moving beyond Volatility

An important caveat from the previous analysis is that we have used the terms “volatility” and “risk” interchangeably, when volatility is an indicator of inherent risk in an instrument, but not risk in itself. In fact, we have fallen short of providing a formal definition of risk. Typically, risk is defined as a probability or threat of damage, injury, liability, loss, or any other negative occurrence that is caused by external or internal shocks. Thus, risk is related to the probability of something bad happening, while volatility simply refers to the amplitude of changes in some exogenous variable.¹¹

In this light, while output volatility may provide a measure of the fundamental risks faced by an economy, and even an estimate of their cost, a better understanding of LAC’s vulnerability to risk requires moving beyond underlying volatilities to other measures of exposure to loss.¹² We take a first step in that direction by looking at a set of the main exogenous determinants of economic growth. While there is little doubt that improving the quality of institutions and stabilizing the economic consequences of the political cycle should be a clear goal among policymakers, this study focuses on the risks stemming from factors out of their direct control. While policymakers cannot alter the underlying characteristics of these external shocks, they can manage their effects through the right combination of preventive, ex-ante and ex-post policies.

The lines below output volatility in Tables 2.1 and 2.2 display exposure to external risks across different regions and LAC’s sub-regions. We group these external risks into economic shocks and natural disasters. Among economic risks, we use the volatility of the terms of trade and trading partners’ economic growth to account for exposure to external real supply and demand shocks, respectively, and private gross capital inflows, sovereign spreads, and sovereign yields to proxy for exposure to external financial shocks. In terms of natural disasters, we compute their frequency of occurrence as an indicator of the economy’s relative exposure to these events. We focus on three main types of natural disasters: earthquakes, storms, and floods.¹³

As shown by Table 2.1, these additional statistics on economic shocks and natural disasters are fully consistent with our previous results: compared to advanced economies, the region is clearly and consistently more exposed to a full range of different external risks. Moreover, these new results lead to a clear conclusion: in terms of overall external risks, LAC is among the riskiest regions in the world.

¹¹ A perfect-foresight model with volatile endowment is the best example of the difference between risk and volatility. Such a model may exhibit enormous volatility but risk is zero (see Végh, 2013).

¹² We find ample evidence in the literature that high volatility has negative effects on growth or is at least closely associated with lower growth. A potential direct mechanism linking high macroeconomic volatility to lower growth comes from its negative effect on investment (see Aizenman and Marion, 1993 and Servén, 1998). From a theoretical point of view, a model with a stochastic endowment could lead to volatile consumption (in a closed economy or a small open economy with incomplete markets). In this case, volatility is a potentially good proxy for risk.

¹³ The category storms includes three types of storm systems: tropical cyclones, extra-tropical cyclones, and convective storms. Hurricanes are generally included as tropical cyclones, but we also include the two latter categories because they can produce as much damage as the first one.

Specifically, in terms of external economic risks, LAC endures almost four times as much terms of trade volatility as Advanced Economies, almost three times as much as Emerging Europe, and not far from twice as much as Emerging Asia. Among LAC's sub-regions, Central America and South America and Mexico are the ones with the most volatile terms of trade. LAC's exposure to real external demand (i.e., main trading partners' growth) is slightly higher than in Advanced Economies but in line with other emerging markets.

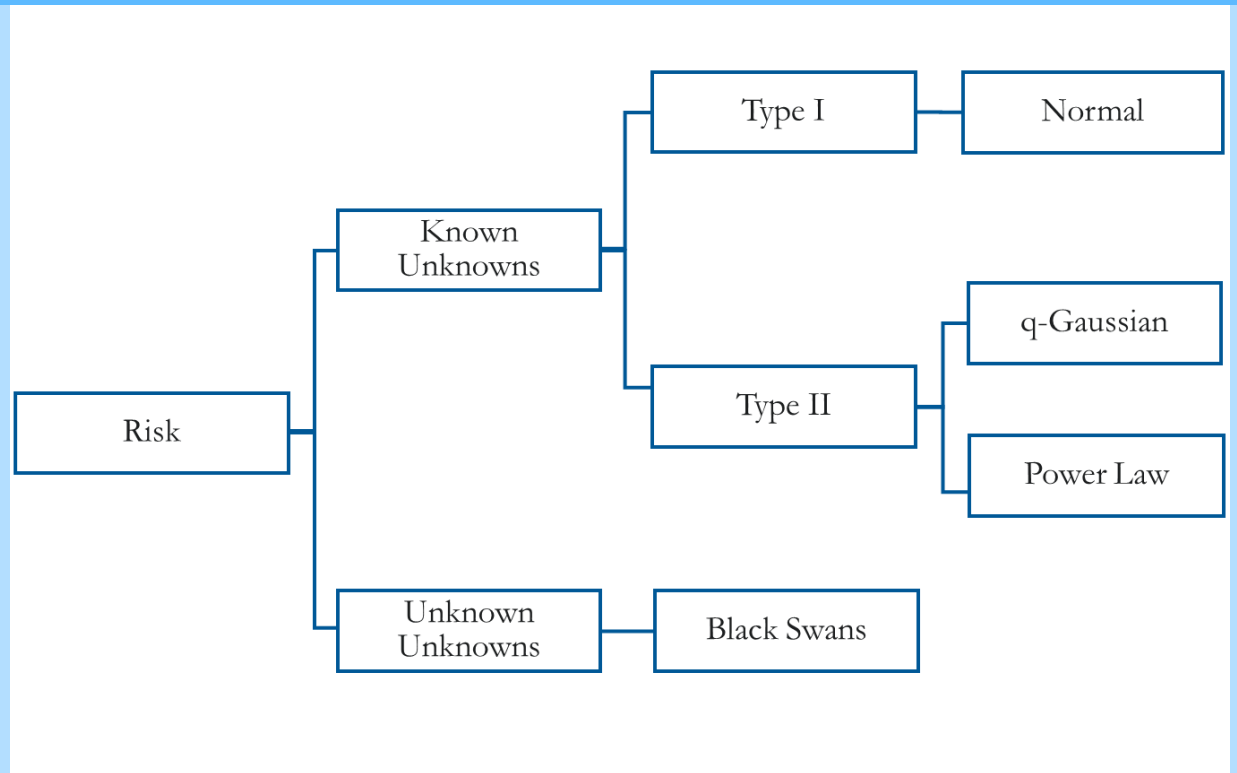
Unfortunately, in terms of exposure to external financial shocks, LAC is once more at the top of the list with Emerging Asia. Volatility of private gross capital inflows (relative to potential GDP) for the whole region is the highest among all emerging markets (together with Emerging Asia). Among sub-regions, South America and Mexico endure about twice as much the volatility of private gross capital inflows experienced by Advanced Economies. In terms of sovereign spreads, which are usually associated with investors' views on the riskiness of domestic markets, LAC's average spreads are not only much higher than those of Advanced Economies but also considerably higher than those in other regions such as Emerging Asia and Emerging Europe. In particular, the Caribbean displays average spreads as high as those in Sub-Saharan economies.

LAC also ranks consistently among the most exposed regions to each type of natural disasters. It is worth highlighting the exposure of the Caribbean to storms and that of South American countries and Mexico to earthquakes. A summary of the exposure and vulnerability to this set of natural disasters is captured by the "World Risk Index", which comprises four components: vulnerability, susceptibility, coping capacities, and adaptive capacities. Unfortunately, the region's scores are among the highest and only surpassed by Sub-Saharan Africa and Emerging Asia. In terms of LAC's sub-regions, Central America scores by an ample margin the highest overall risk.

A Primer on Risk

This section takes a step back and tackles the fundamental idea that not all randomness is the same, especially when it comes to finding ways to protect an economy against it. To set the stage, we will first introduce Knight's (1921) distinction between risk and uncertainty and then re-label it in terms of a more modern terminology (known unknowns versus unknown unknowns), which brings more clearly the underlying ideas. To illustrate the main concepts, we will examine specific distributions as we go along, ranging from the familiar normal distribution – where all moments are well-defined – to others where not all moments are finite, which greatly complicates the task of predicting future values and/or insuring. In fact, we will see that, depending on the number of finite moments, an economy will be able to secure different degrees of insurance. Figure 2.1 illustrates how the discussion of risk will be organized in the report.

FIGURE 2.1. Different Types of Risk



Source: Authors' elaboration.

Risk versus Uncertainty or Known Unknowns versus Unknown Unknowns

The simple (and simplistic) approach used in the previous section led us to conclude that LAC is disproportionately exposed to both external shocks and natural disasters. Hence, there is a need to provide policymakers with all the available tools to reduce the exposure to such shocks. But before being able to dig deeper into risk management, we need to understand much better the nature of risk and its different guises.

The first key step towards a better understanding of risk is to distinguish between risk and uncertainty. This distinction is subtle but important. While not the first one to think about the problem of risk and uncertainty in economics, Knight (1921) was the first to explicitly differentiate between the two concepts.¹⁴ In his famous 1921 essay, Knight gave risk a measurable nature in which “... all the alternative possibilities are known and the probability of occurrence of each can be accurately ascertained.” In contrast, he viewed uncertainty as applying to situations where all possibilities are not foreseeable with any degree of confidence. In other words, Knight viewed risk as randomness that could be neatly described in terms of distributions and uncertainty as randomness that could not.

¹⁴ Earlier thought on the problem of uncertainty and risk in economics can be found in connection to insurance, speculation, and entrepreneurship. For a very general discussion of uncertainty, see Leslie (1879), Haynes (1895), Ross (1896), Pigou (1912), and Lavington (1912, 1913).

While Knight’s conceptual distinction between risk and uncertainty is here to stay, his terminology (risk versus uncertainty) is not. In fact, more often than not, most modern literature (both academic and financial) uses both terms interchangeably. Therefore, to avoid any confusion, from now on, we will use the more modern terminology of *known unknowns* (risk in Knight’s terminology) and *unknown unknowns* (uncertainty in Knight’s terminology) and think of them as simply two different types of risk, as captured by Figure 2.1. This terminology is also attractive because it makes immediately clear the ideas behind the concepts: known unknowns refer to random variables (the “unknowns”) whose distribution we know, whereas unknown unknowns refer to random variables (the “unknowns”) whose distributions we do *not* know. For example, while we cannot exactly predict the height of a person chosen at random, we can fully characterize the distribution of the height of the population in terms of the normal distribution (see below). In contrast, not only can we not exactly predict the occurrence of another September 11-type terrorist attack, but we do not even have the vaguest idea of what distribution could characterize such an extreme event. While the terminology of known unknowns versus unknown unknowns was introduced to the public at large in a now famed interview by Donald Rumsfeld in 2002, the terms were already being commonly used by intelligence professionals and seem to have been introduced by psychologists Joseph Luft and Harrington Ingham in the mid-1950’s.^{15 16} Finally, notice that the concept of unknown unknowns corresponds, if the size of the shock is large enough, to the “black swan” events featured in the famous 2007 book by Nassim Taleb.

On the Impossibility of Insuring against Unknown Unknowns

As already mentioned, the differences between known unknowns and unknown unknowns are far from inconsequential, especially for risk analysts and policymakers. Known unknowns are, by definition, characterized by an ex-ante known random distribution. Such information opens up the possibility of hedging/insuring against this type of risks. In contrast, unknown unknowns (or black swans in Taleb’s terminology) do not have, by definition, an ex-ante stochastic distribution. This makes it virtually impossible to hedge/insure against such events.

Some examples of black swans are presented in Table 2.3. The unique nature of these events and their dramatic effects on the economy, society, and course on history make them excellent examples. Each one of these events was unimaginable shortly before they happened, which implies that any ex-ante attempts to mitigate their effects were virtually impossible.

¹⁵ In a February 12, 2002, interview, Secretary of Defense Donald H. Rumsfeld said “... we also know there are known unknowns; that is to say, we know there are some things we do not know. But there are also unknown unknowns – the ones we don’t know we don’t know. And if one looks throughout the history of our country and other free countries, it is the latter category that tend to be the difficult ones.” Even though he was ridiculed by some for his presumably obscure language, Secretary Rumsfeld was, of course, exactly right. It is the things that we do not know we do not know (9/11 being again an excellent example) that change history and are the hardest to deal with.

¹⁶ See Luft and Ingham (1955) and Pringle *et al.* (2016).

TABLE 2.3. Black Swans in Practice

Event	Date	Description
<i>Black Death</i>	14th Century	The Black Death was a deadly pandemic during the Middle Ages, mostly associated to an outbreak of the bacterium <i>Yersinia pestis</i> . Various sources estimate the death toll around one third of Europe's population, with a similar calculation for the surrounding regions.
<i>The Long Depression</i>	1873-96	Following a series of financial failures in Austria that quickly spread to the rest of Europe and the United States (namely, the Panic of 1873), a prolonged period of generalized deflation and economic recession began. This episode was considered the first major crisis of globalization.
<i>World War I</i>	1914-18	The assassination of Austrian Archduke Franz Ferdinand in Sarajevo on June 28, 1914, led to a diplomatic crisis that escalated into the declaration of war of Austria-Hungary against the Kingdom of Serbia. A series of international military alliances went into effect and soon the major powers engaged in the first industrialized global war.
<i>Spanish flu pandemic</i>	1918-19	The Spanish flu pandemic, the deadliest in modern history, is estimated to have infected around 500 million people globally, with a calculated death toll of 20-50 million.
<i>The Great Depression</i>	1929-39	The Great Depression was the deepest economic contraction of the industrial era. Following the Wall Street crash of 1929, consumer and investor confidence plummeted, triggering a period of worldwide deflation, production decline, and high unemployment. Between 1929 and 1933, the United States' real GDP fell by approximately 30 percent and, by 1933, nearly 25 percent of its workforce was unemployed. The deterioration of global living standards became a landmark in modern history.
<i>Rise of Hitler and Nazism</i>	1933-39	Adolf Hitler joined the German Workers' Party in 1919 and, by 1933, had achieved the position of Chancellor. Guided by the principles of nazism, the country began a process of re-armament. A mixture of factors, including the reluctance of European powers to start a new armed conflict, the inability of the League of Nations to impose economic sanctions, and a global political rebalancing, contributed to the unthinkable scenario of bringing the world on the verge of a second global war.
<i>First Oil Crisis</i>	1973-74	In October 1973, members of the Organization of Arab Petroleum Exporting Countries implemented an oil embargo against the nations that supported Israel during the Yom Kippur War. The price of the oil barrel quadrupled and the episode was labeled as the "first oil crisis".
<i>Collapse of the Soviet Union</i>	1991	In the early 1980s, the Soviet Union was the largest nation in the world, a nuclear military power, and a consolidated Communist bureaucracy. In the late 1980s, however, a series of factors led to its sudden dissolution in 1991, generating a political, social, economic and military recomposition across the globe.
<i>9/11 Terrorist Attacks</i>	2001	On September 11, 2001, members of al-Qaeda hijacked four passenger airplanes and executed suicide attacks in the United States. Two airplanes brought down the Twin Towers of the World Trade Center. The event marked a turning point in the global fight against terrorism.
<i>Global Financial Crisis</i>	2008	In 2008, Lehman Brothers declared bankruptcy, aggravating the contagion of a subprime mortgage crisis. Due to the interconnection of the global financial system, the shock quickly spread, leading to a generalized credit crunch and sowing the seeds of a global recession.
<i>The Arab Spring</i>	2010-12	Starting in December 2010, Middle East and North Africa, until then characterized by the stability of authoritarian regimes, experienced massive social uprisings. Democracy, more economic freedom, and the protection of human rights were among protestors' main requests. The demonstrations reshaped the regional political scene, including ousting of governments, violent repression, implementation of reforms, and civil war.

Source: Authors' elaboration.

To highlight the difficulty of implementing precautionary policies against unknown unknowns, consider a policymaker who decides to set aside valuable resources to protect the country against something unthinkable with unimaginable consequences.¹⁷ It is safe to conjecture that he/she will be out of office before long. Even ex-post, any kind of precautionary saving put aside to cover for black swans would probably be a waste. Suppose that the policymaker decides to set aside 100 billion dollars in case of a nuclear winter or most extinction of life after a meteorite strike. These billions of dollars

¹⁷ Self-insurance seems the only plausible way to act since there are no parameters to fill an insurance contract.

would have been better spent for today's needs rather than saved for such an improbable event (which may never occur for several generations and, even if it did, can inflict damages that are simply impossible to calculate).

The above does not mean we should ignore potential black swans. Quite to the contrary, given their potentially life-changing nature, policymakers should be aware of this type of risks and prepare as well as possible to deal with their fallout. Since standard preventive measures would not work for these types of shocks, policymakers would seem to have no choice but to rely exclusively on ex-post measures. However, some general "good practices" like strengthening institutions and markets as well as strong diplomatic ties and global/regional economic agreements may have a positive effect on countries' ability to deal with black swans.

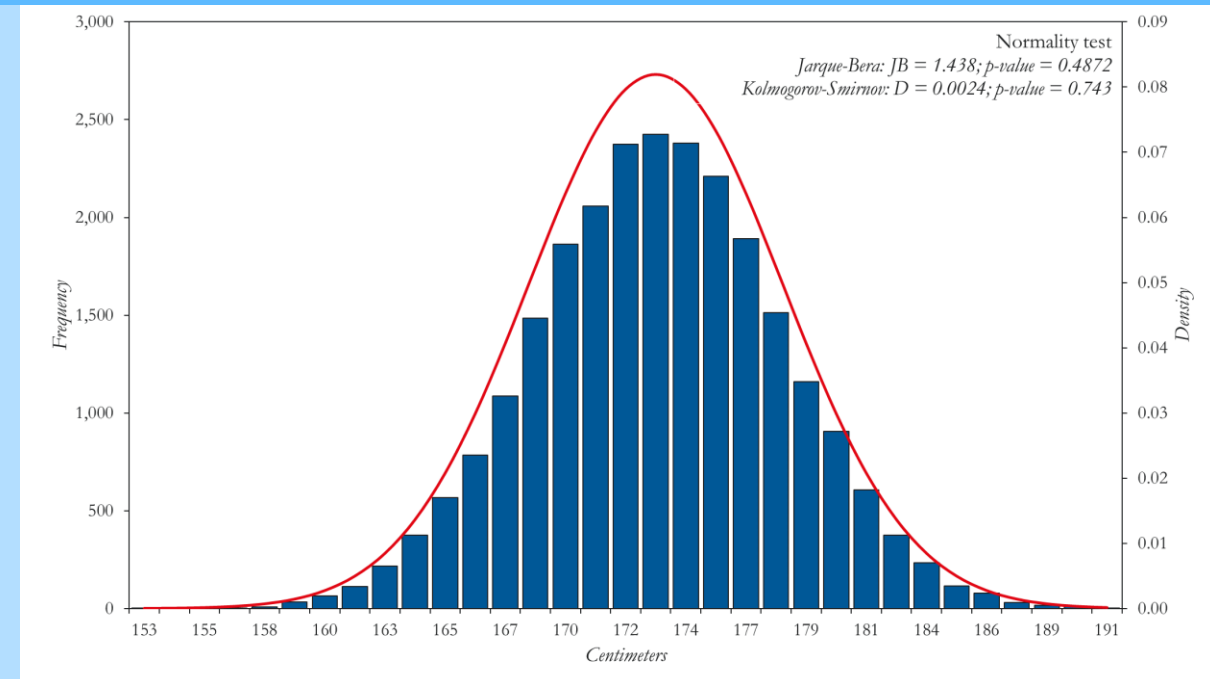
On Bell Curves and Fat Tails

Turning now to the known unknowns (Figure 2.1), it is worth noting that not all risks are the same. A defining characteristic of a risky variable is its underlying distribution. We group the range of possible underlying distributions into bell curves (i.e., Normal or Gaussian distributions), which we refer to as Type I risk, and fat tails (distributions belonging to the Pareto family), which we refer to as Type II risk. This grouping is neither random nor capricious since risks that follow bell curve-type distributions will be relatively easy (and cheap) to hedge, while risks characterized by fat tail-type distributions will be more complex (and typically more expensive) to insure against, if at all.

The complexity and cost of insurance is directly related to the ex-ante ability to accurately predict future values of the random variable. The accuracy, in turn, will depend on the ability to precisely calculate the moments of the underlying distribution and the stability of those moments over time. It is easy to show that while it is relatively simple to estimate the moments of a bell curve and that they are stable over time, it is much harder to do so for, say, Pareto-type distributions. To illustrate this point, consider the distribution of height for twenty-five thousand randomly picked individuals as represented in Figure 2.2. As can be seen, this human attribute (as other traits in nature) clearly follows a normal distribution. Suppose that the next person we add to this distribution turns out to be three meters tall or twenty-six standard deviations above the mean. Such a case has never been recorded in history and would be beyond surprising.¹⁸ The normal distribution would tell us that the probability of finding an individual with height more than twenty standard deviations to the right of the mean is extremely small but, crucially, not zero. What makes the bell curve attractive is that, given a large number of observations and their relatively small deviation from the mean, adding the three-meter-tall individual to the distribution will not affect its sample moments in the least (the mean will remain at 172.7 cm and the standard deviation will increase from 4.7 to 4.8 cm).

¹⁸ American-born Robert Pershing Wadlow (1918-1940) is the tallest person recorded in history. Wadlow reached 8 ft 11.1 in (2.72 m) or twenty standard deviations above our sample mean.

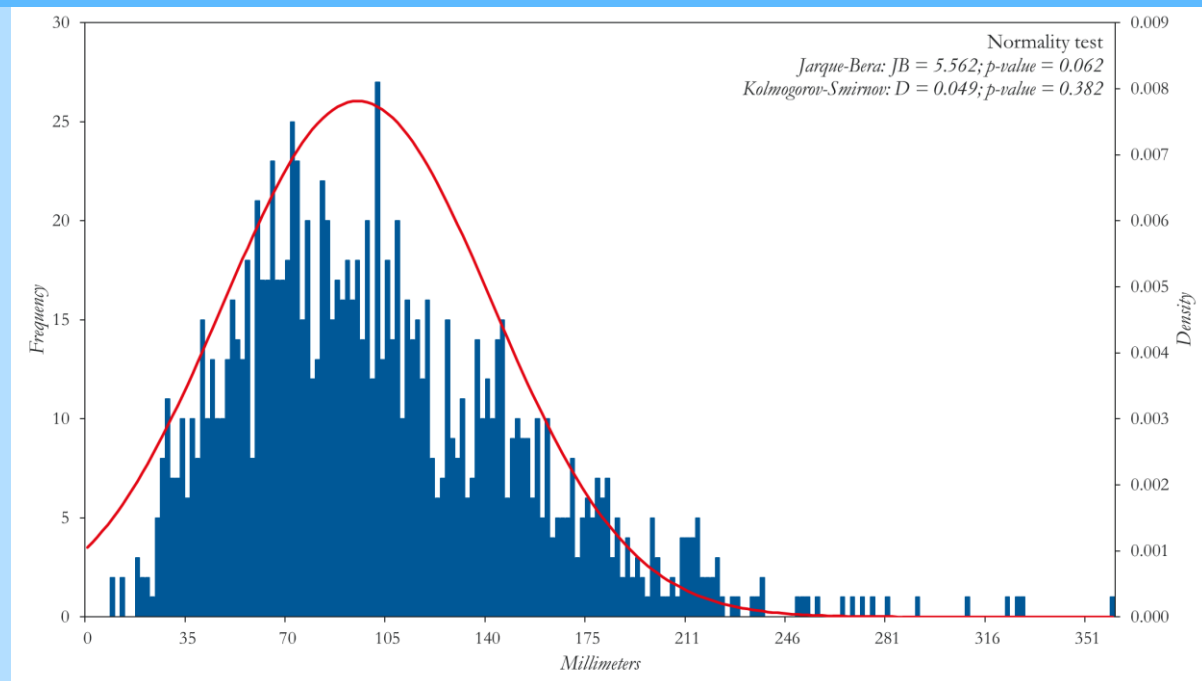
FIGURE 2.2. Poster Child of a Type I Event: Distribution of Human Height



Note: Data based on a growth survey of 25,000 children from birth to 18 years of age from Hong Kong. Source: Authors' computations based on data from Statistics Online Computational Resource (UCLA).

A more relevant example for policymakers in developing countries would be the monthly quantity of rainfall. As an example, Figure 2.3 shows the underlying distribution of rain in Uruguay, a country heavily dependent on agricultural exports. Rain appears to follow a normal distribution with an average of 102.3 mm and a standard deviation of 51.1 mm. Nature, of course, limits the amount of rainfall. To illustrate these bounds, imagine the most extreme rainy month possible where heavy rain (7 mm per hour) falls 24 hours, seven days a week, for every single day of the month. We are talking about a Noah's Ark-type of cataclysmic event here. Under these extreme circumstances, the total amount of rainfall would be around 5,000 mm per month, about fifty times higher than the mean. While this is obviously a very large amount of rain, it is not large enough to bring significant changes to the sample mean (which would raise from 102.3 to 102.7 mm). Insuring against these types of “well-behaved” Type I risks should be relatively easy and cheap.

FIGURE 2.3. Distribution of Rainfall in Uruguay



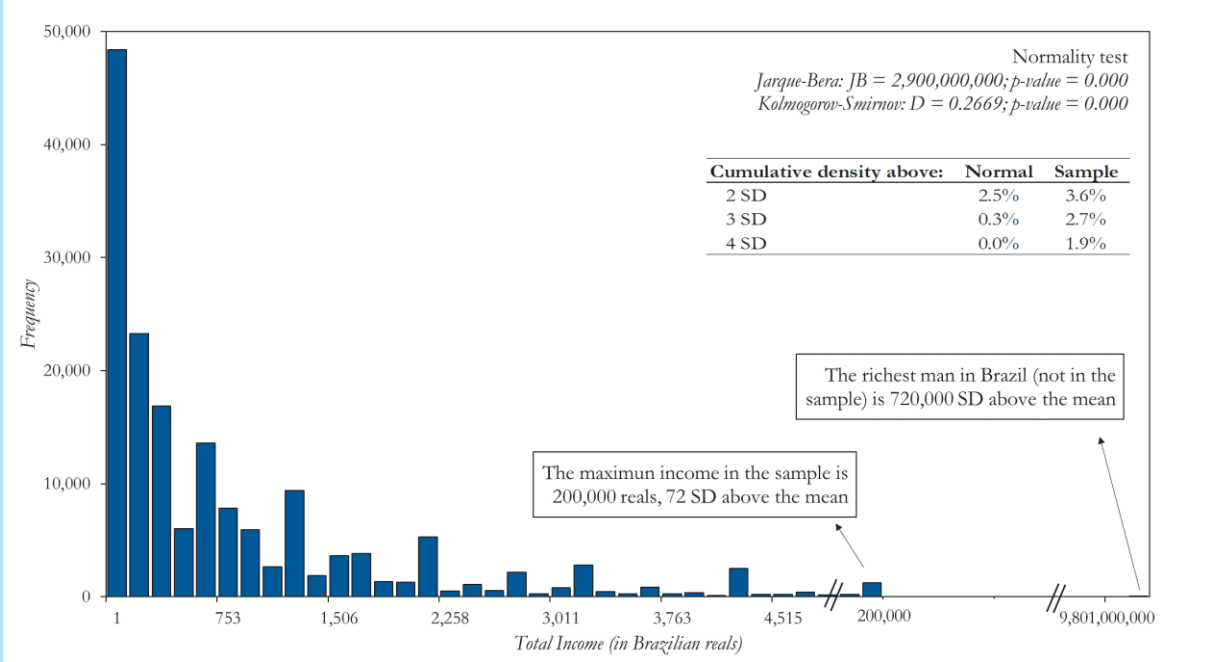
Note: Monthly data for the period 1916-2015. Source: Authors' computations based on data from Climate Change Knowledge Portal (World Bank).

In contrast to the “well-behaved” Type I risks, as soon as we start thinking about risks characterized by Type II distributions, we quickly realize that we are not in Kansas anymore. Consider, for example, the distribution of income in Brazil. Following the example used by Jan Pen in his 1971 treatise on income distribution, suppose that we could congregate all Brazilian income earners in Rio’s Sambodromo to participate in a one-hour long parade where the lowest income earners walk first and the highest last.¹⁹ To relate to the height example above and to gain visual perspective, imagine that the height of each participant is proportional to his/her income. Let us also assume that we, spectators, are of average height. While the exercise seems straightforward, it will turn out to be the strangest parade in history. For a very long while, you would only see incredibly small people (just inches tall), an amazing parade of dwarfs. It would take more than forty-five minutes for participants to reach the same height as spectators. In the final minutes, incredible giants taller than mountains would appear. Finally, someone like Jorge Paulo Lemann (the richest man in Brazil) would close the show. Lemann’s lower thigh would be above the Karman Line, in other words, two thirds of his body would be in space.

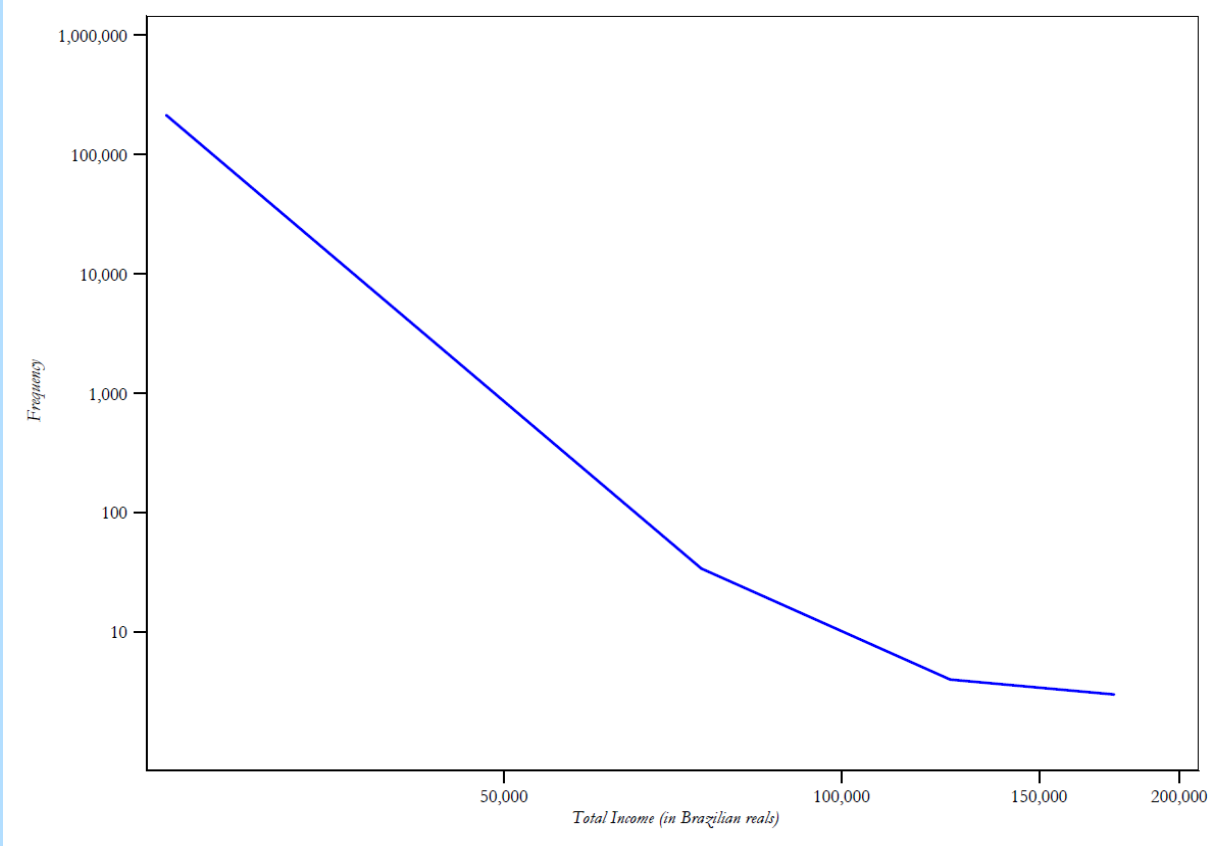
¹⁹ See Pen (1971).

FIGURE 2.4. Poster Child of a Type II Event: Distribution of Total Income (Brazil, 2015)

PANEL A. Histogram



PANEL B. Logarithmic Scale



Source: Authors' computations based on data from SEDLAC (CEDLAS and World Bank).

Brazil's income distribution, portrayed in Figure 2.4, Panel A, clearly follows a Pareto-type distribution (e.g., a power-law distribution) since an individual like Lemann, 720,000 standard deviations above the mean, would be unthinkable in a normal distribution.²⁰ Instead, given the fat tails of a Pareto-type distribution, such extremely high income is not that improbable. More importantly, adding a “Lemann” type event to a sample distribution would dominate its underlying moments changing the average from 1,747 to 45,774 reals and the standard deviation from 2,757 to 20,327,381 reals. As Figure 2.4 shows, plotting the typical histogram (Panel A) with power-law type of distributions is not that helpful. A very large number of observations are bunched in the early part of the distribution and, as the value of income rises, the frequency quickly drops to display a very long tail with seemingly no mass below it. This graph is quite misleading and does not help us appreciate the interesting story behind the relatively heavy tails of this distribution. To correct for this problem, the literature typically displays these types of distributions in logarithmic scale. As Panel B in Figure 2.4 shows, once in logarithmic scale, the Brazilian income distribution appears as a linear function with a moderately flat slope which means that while the x -axis numbers grow at a very high speed, the frequency of such observations decreases slowly. In other words, the slow speed at which the frequency of these observations decreases with size allows us to fit shockingly large events such as “Lemann” inside the realm of the highly improbable but not at all impossible.

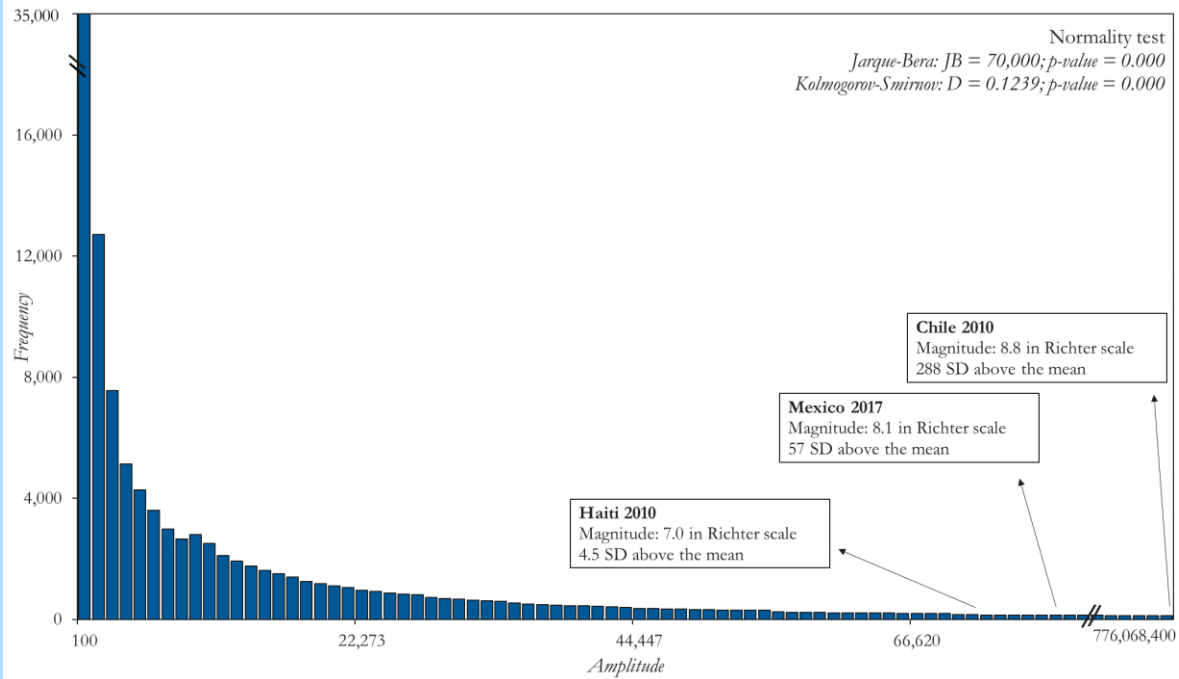
Two other examples of Type II risks relevant for emerging markets are the intensity and economic effects of natural disasters and the size of private international capital flow reversals (“sudden stops”), both of which can have serious effects.²¹ These extreme natural and financial events clearly belong to this strange world of power-law type distributions. As an example of natural disasters, Figure 2.5, Panel A looks at the distribution of earthquake intensity measured by the Richter scale, which is defined as the logarithm, base ten, of the maximum amplitude of motion detected in the earthquake. The x -axis in Panel B thus represents the logarithmic scale of amplitude. Using historical data for LAC earthquakes since the beginning of the 20th century, we observe that most tremors are low-intensity events with values ranging between three and four in the Richter scale. Nevertheless, we do observe larger events ranging from five to six in the Richter scale with relatively high frequency. Given its logarithmic nature, it is worth reminding ourselves that an earthquake of intensity six in the Richter scale is one thousand times more powerful than the typical quake of magnitude three. Moreover, United States Geological Survey (USGS) experts estimate a 93 percent probability of an earthquake with magnitude between seven and eight in the Richter scale hitting California before the year 2045. An earthquake of magnitude eight in the Richter scale would be an event one hundred thousand times more powerful than a typical earthquake of magnitude three in the same scale. As with “Lemann” events in Brazil's income distribution, the magnitude-eight event would dominate the moments in the sample distribution of earthquake intensity.

²⁰ While we keep referring to power-law distributions in the text, we are aware that there are a large number of Pareto-type distributions that would also fit the profile of Type II risks. Given the scope of this report, however, we abstract from digging much deeper into the statistical formalities required to describe all potential distributions behind Type II risks and instead use the q -Gaussian and power-law distributions as concrete examples of a larger universe of distributions.

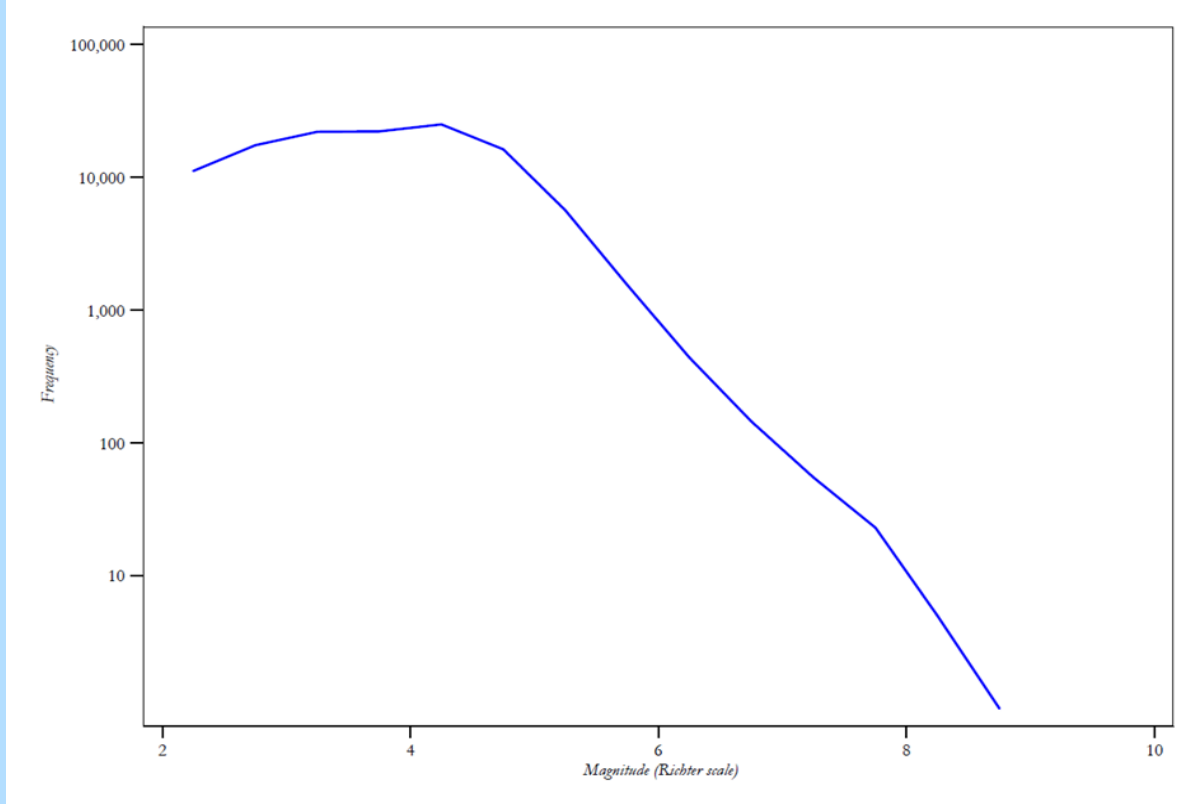
²¹ See, for example, Calvo (1998) and Loayza *et al.* (2012).

FIGURE 2.5. Distribution of Magnitude of Earthquakes

PANEL A. Histogram



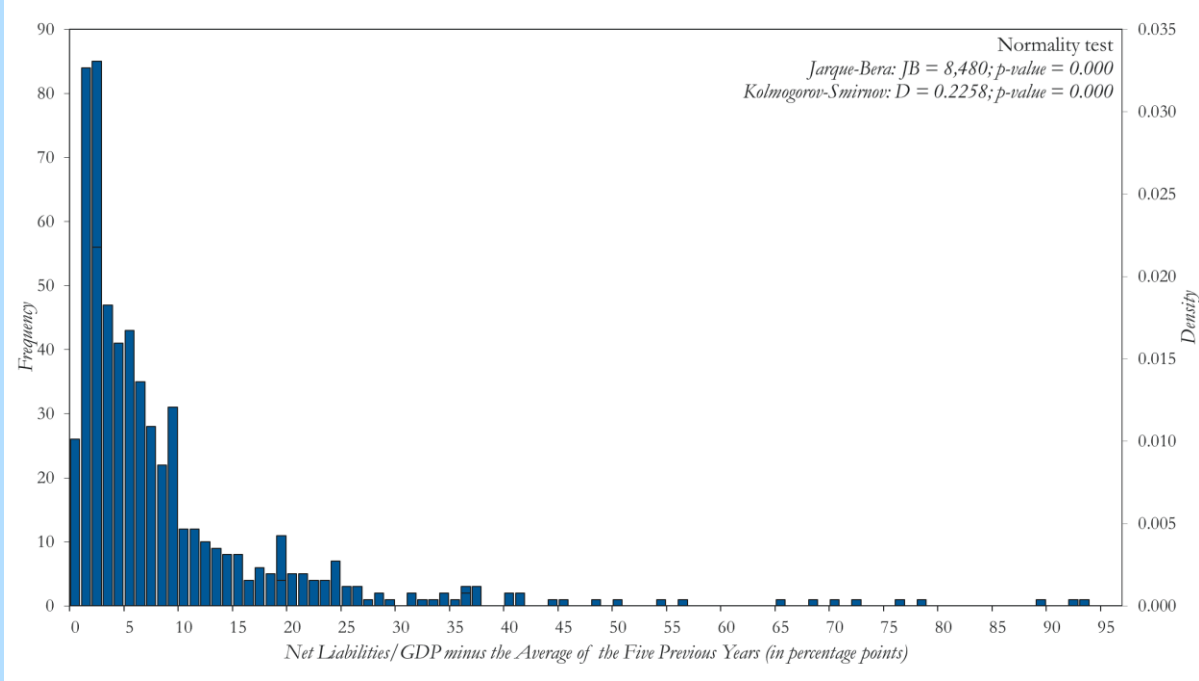
PANEL B. Logarithmic Scale



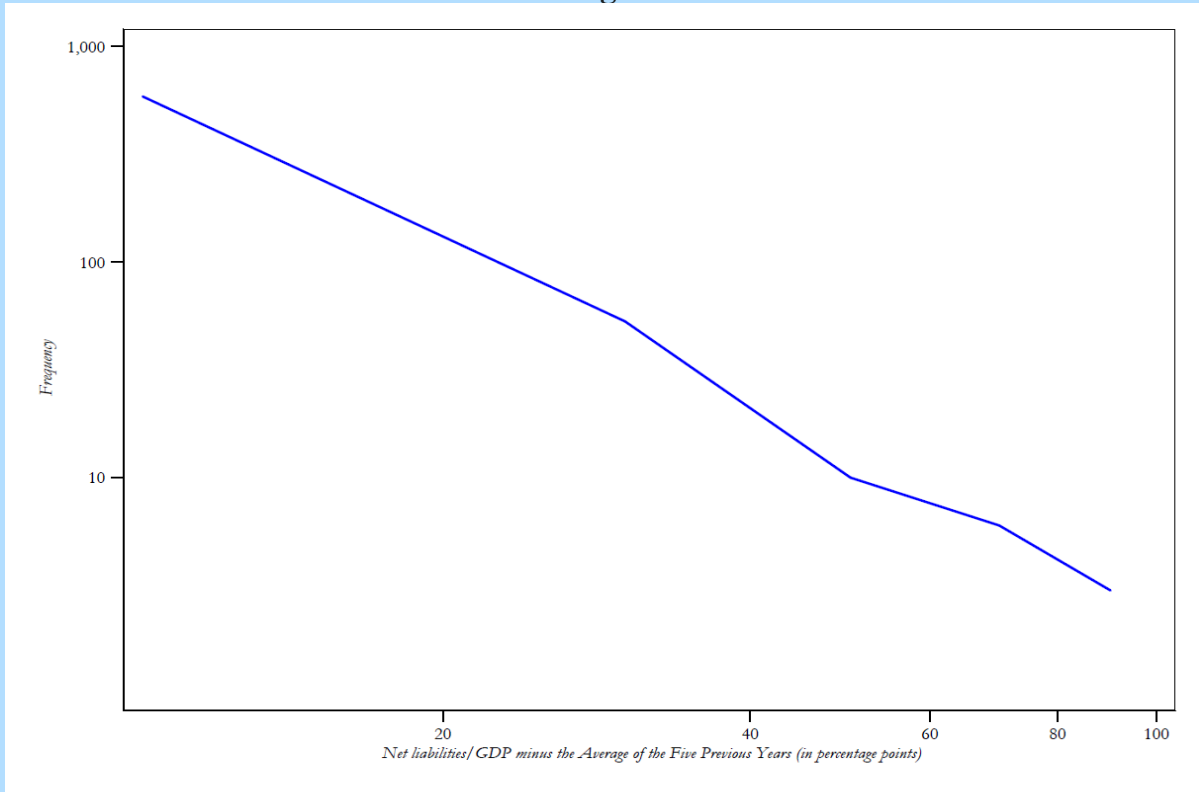
Source: Authors' computations based on data from the Northern California Earthquake Data Center, UC Berkeley Seismological Laboratory.

FIGURE 2.6. Distribution of Intensity of Sudden Stops

PANEL A. Histogram



PANEL B. Logarithmic Scale



Notes: A sudden stop is defined as occurring when portfolio investments and other investments' net incurrence of liabilities (as percentage of GDP) of the private sector decline below the average of the previous five years by at least 1.5 standard deviations. The exclusion window between episodes is one year. The intensity is measured as the difference between the ratio of net incurrence of liabilities (as percentage of GDP) and the average of that ratio for the previous five years. Sources: Authors' calculations based on data from the BOP-IMF and WDI.

On sudden stops, Figure 2.6 (Panels A and B) shows that these events also exhibit traits of a power-law distribution. Most observations are bunched around the lower bound (three percent of GDP), while there is a relatively large number of events on the tail.

When Type II Risks Dress up like Type I: Costly Cases of Mistaken Identity

Rainfall (droughts) and earthquakes give us clear-cut examples of two very different types of risk that countries may face. Unfortunately, a very significant set (if not the clear majority) of economic risks faced by developing countries are not that clear-cut. A good example of risks that can easily fool both markets and policymakers are those associated with changes in asset prices.

Take for example changes in equity prices. Panel A in Figure 2.7 plots the returns of the Dow Jones Industrial Index, which represents a weighted average of equity prices of the largest firms traded at the New York Stock Exchange. To the untrained eye, the underlying distribution clearly seems to follow the classical bell-shaped curve. When we test for normality, however, we can firmly reject the null hypothesis of a normal distribution because of too much probability mass on the tails. In other words, there are too many tail events in the distribution for a normal distribution to hold. While we can safely discard the normal distribution, the distribution shown in Figure 2.7, Panel A is still quite different from the power-law type of distribution displayed by the poster child of Type II risk, income (Figure 2.4).

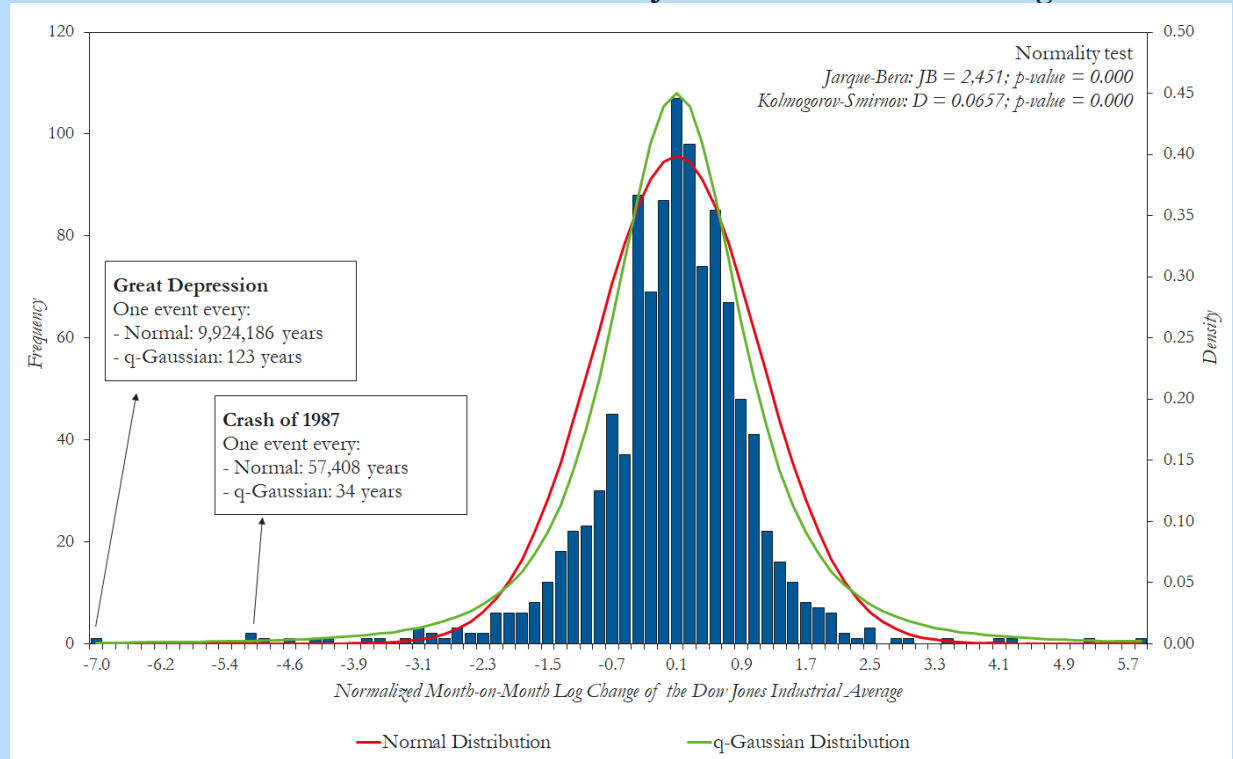
To help us think about this puzzle, we can apply the simple rule that while a power-law-type distribution can easily disguise itself as a normal distribution, the opposite is not true. Some recent studies have shown that the driving noise in stock price series and other financial assets may be characterized by Tsallis-type distributions.²² These distributions fit the data very well due to their bell curve behavior around the mean but power law behavior around the tails.²³ Such power tails immediately render shocks to asset prices Type-II risk events. To illustrate this point, Figure 2.7, Panel A draws the probability density function of the sample normal distribution and a q-Gaussian distribution with the parameters used in Michael and Johnson (2003). While both distributions look very similar, we can clearly see that the q-Gaussian not only captures better the large density of small observations (around zero) but, more fundamentally, allows for relatively high probability of very large events (fat tails). As Panel B of Figure 2.7 shows, changes in commodity prices also fit in this family of Type II risks dressed as Type I.

²² See Borland (2002), Tsallis *et al.* (2003), Gell-Mann and Tsallis (2004), and Tsallis (2009).

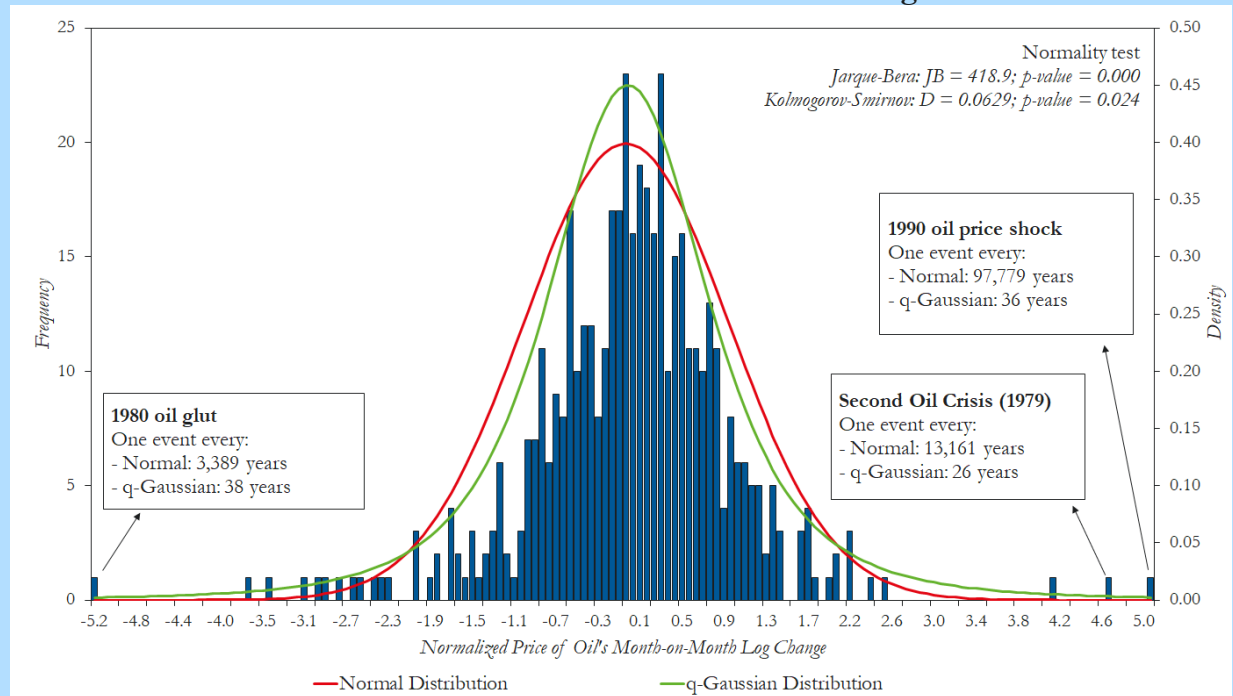
²³ Tsallis distributions are obtained as Box-Cox transformations of standard distributions. Thus, the q-Gaussian is derived from a Box-Cox transformation of a Gaussian distribution. Tsallis *et al.* (2003) find that the S&P 500 returns can be fitted with a Tsallis distribution with entropic index $q=1.5$ ($q=1$ would, in the limit, converge to a normal distribution). Entropy measures the degree of randomness in the system. This entropic index in the Tsallis distribution is consistent with having tails similar to those of a power law distribution with an α between 3 and 4 (see equation 2.1. below).

FIGURE 2.7. When Type II Risks Dress up Like Type I

PANEL A. Distribution of the Dow Jones Industrial Index Changes



PANEL B. Distribution of Price of Oil Changes



Notes: Dow Jones series from January 1928 to May 2018. Oil price data from January 1979 to April 2018. Sources: Authors' computations based on data from Bloomberg and World Bank Commodity Price Data (Pinksheets).

At this point, it is crucial to highlight that confusing these two types of risk could be extremely costly and even potentially disastrous for market participants. To see why, we can use the estimated normal distribution to compute how often events such as the Great Depression take place (with falls of at least 36.7 percent of the equity value or 7 standard deviations below the mean). The result will be one such event every 9,924,186 years. Meanwhile, the q-Gaussian will predict one event every one hundred and twenty-three years. Some may argue that the error of assuming a normal distribution, or in other words, ignoring potential Great Depression-size shocks is not that high since, even if the q-Gaussian was the true underlying distribution, there would be a good chance that you will not encounter such event in your career even if you work for a long time. The problem for the fooled/confused traders grows substantially when we look at the next class of big events. The “Crash of ‘87” type of events (with drops in equity value of at least 26.4 percent or 5 standard deviations) are still big enough to cause mayhem among unprepared market participants. Indeed, using the normal distribution, an event such as the Crash of ‘87 would occur every 57,408 years. In sharp contrast, the q-Gaussian predicts one such event every 34 years. Thus, ignoring these events will be awfully costly for any seasoned market professional. Moreover, even occasional market participants would face significant probabilities of suffering large shocks and, thus, large losses by mistaking the identity of the relevant risk.

Two famous examples of the potentially huge costs of ignoring the possibility of extreme events are the Long Term Capital Management (LTCM) and the American International Group (AIG) collapses after the 1998 Russian crisis and the 2008 Great Recession, respectively. In the case of LTCM, while the collapse of Russian sovereign bonds, together with LTCM’s inability to carry out currency hedging due to the Russian banks’ decision to stop trading currency was a tough direct hit on their balance sheet (losing about two billion dollars in equity), the death blow came from a completely non-expected source. Russia’s decision to default on its government obligations created a worldwide “flight to liquidity.” This increased significantly the cost of liquidity in the U.S. and thus reduced the value of the fund’s short positions relative to their long positions. Given the large leverage faced by the fund, this turned out to be an enormous unhedged exposure to a single risk factor. LTCM traded liquidity premiums as a Type I risk when it was a Type II all along and failed to hedge against large jumps in the premiums. This error greatly contributed to the ultimate collapse of LTCM and a domino effect that threatened to bring down the whole financial system.

While a vital component of the LTCM downfall was the careless assessment of the tail risk on a relatively obscure financial spread, AIG’s downfall (as many other huge financial institutions during the Great Recession) was directly related to the willful disregard of the possibility of very large shocks and generalized changes in the U.S. real estate and equity markets. AIG started issuing a new set of insurance instruments called credit default swaps (CDS) to cover for default risk on collateralized debt obligations (CDOs) which bundled mortgages, many of them sub-prime (i.e., with high default risk). As mortgages started to suffer massive defaults and real estate prices collapsed, AIG found itself losing billions of dollars and incapable of meeting its insurance obligations.

As mentioned above, a key driver in the distinction of different types of risk is the amount of information provided ex-ante by the underlying distribution. Following the same logic, we can

distinguish among the different Type II risks described in this section. As it turns out, given its simple probability density function,

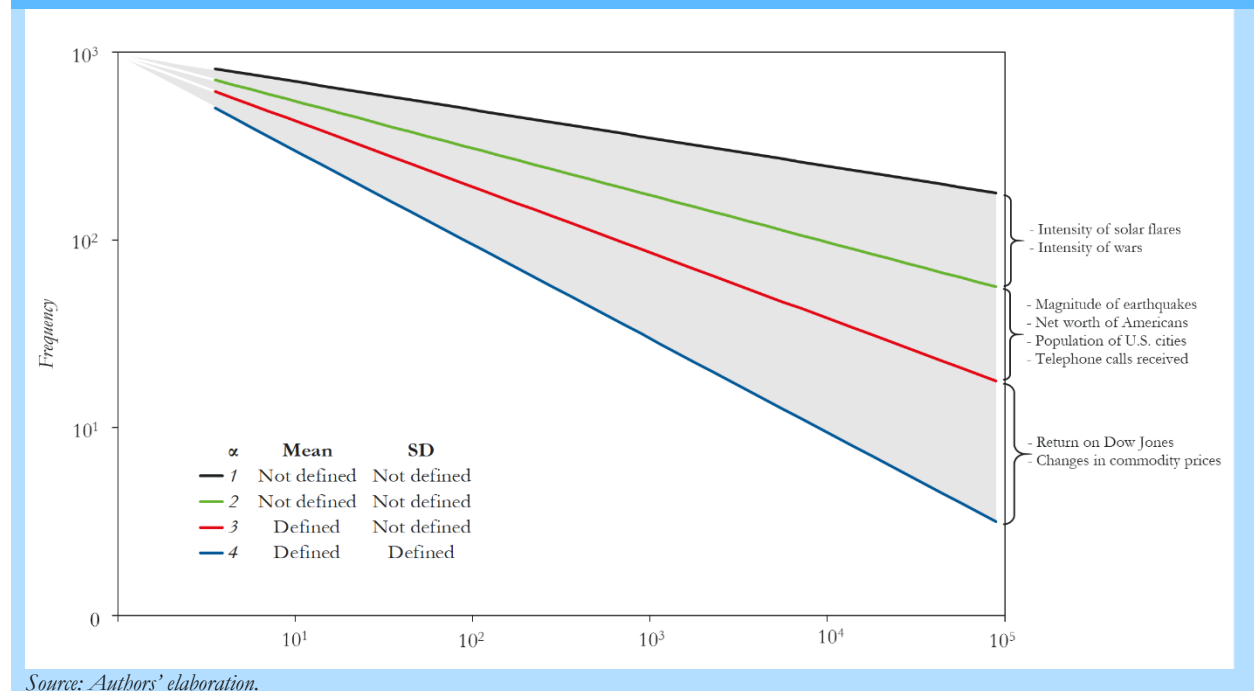
$$f(x) = \frac{c}{x^\alpha},$$

the power-law distribution gives us a simple rule in terms of the amount of information that it provides. To see this, take logarithms and rewrite the above equation as

$$F(x) = \log(c) - \alpha \log(x), \tag{2.1}$$

where, by definition, $F(x) \equiv \log[f(x)]$. This last equation makes clear that, when expressed in terms of logarithms, the power-law distribution becomes a negatively-sloped line. As α gets smaller, the slope becomes flatter (which implies fatter tails) and more moments become indefinite (Figure 2.8). It can be shown that the amount of finite moments equals the exponent of the power-law distribution, α , minus two. Figure 2.8 shows the power law distribution for different values of α , ranging from one to four. For values between one and two, the distribution has tails so fat (since a flatter line in the logarithmic scale implies fatter tails) that no finite moments (even a mean) may be found. For values of α between two and three, we could find examples such as earthquakes and sudden stops. For these type of events, a finite mean can be estimated, but the tails are so fat that there is no finite variance. In light of this limited information, it will be difficult to insure against these types of risk (as will be discussed in the next chapter). Finally, for values of α between three and four, we can find examples such as stock and commodity prices. In this case, distributions are well-defined, which implies that economic agents can insure against such risks.

FIGURE 2.8. Power-Law Distributions



How Vulnerable is the Region?

Exposure per se does not necessarily tell us a lot about risk. A fish in the ocean is heavily exposed to water but faces little risk from it. In contrast, a vampire watching the first rays of sun at the crack of dawn has little exposure to the sun but faces enormous risk from it. To put forward a comprehensive analysis of risk in the region, we need to go beyond exposure and talk about the effects of such exposure on the region's welfare. In other words, we need to understand how vulnerable the region is to the type of risks described above.

While rainfall (one of the few economically relevant examples of Type I risks) is an important risk factor for economies with relatively large agricultural sectors, emerging markets are primarily exposed to Type II risks such as international commodity and asset prices and natural disasters.²⁴

The information provided in Table 2.1 gives us a good sense of the region's exposure to such risks relative to industrial countries and other emerging markets. Table 2.1, however, does not provide us with any information as to how vulnerable the region is to such risks. In other words, Table 2.1 is useful when read across rows (comparing exposures to each type of risk across regions) but not so much along columns (evaluating the relative effects of each type of risk on the economy). This section attempts to address such shortcomings by studying the vulnerability to each of the main risks faced by LAC.

Vulnerability to q -Gaussian Shocks

As explained above, an important share of external risk factors follows distributions that resemble bell curves for small values but exhibit fatter tails, allowing for large events with relatively high frequency. Among the more relevant of these risk factors for emerging markets are international commodity and asset prices such as global interest rates and exchange rates. To evaluate the economic impact of these external factors, we need to understand how much they can explain of changes in the region's economic welfare. For the purposes of this section, we resort to real output growth as a proxy for economic welfare.

To capture the full impact of external shocks on any given economy, we must consider the fact that a shock in one of the series can have a direct and contemporaneous impact on output growth but can also lead to lagged indirect effects through changes in other important variables in the economy. Moreover, changes in some variables may be persistent over time leading to dynamic effects on output growth and other variables. To account for all these potentially important mechanisms, we treat the problem as a dynamic set of interrelated equations. Thus, we estimate a structural vector autoregression (SVAR) model for each country with available data. To better account for all potential dynamic mechanisms, we use quarterly data, the highest frequency available. The analysis focuses on a total of 52 economies and covers the period 1960-2017. Based on data availability, we include the

²⁴ Next chapter will explore in detail the tools available to hedge some of these risks.

following LAC countries: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Mexico, Nicaragua, Paraguay, and Peru.

We include three important and plausibly exogenous external determinants in the model: commodity terms of trade (CTOT), the short-run real interest rate in the U.S., and output growth in the U.S. While CTOT and the business cycle in the U.S. capture international exogenous real supply and demand shocks, respectively, interest rates in the U.S. capture changes in global liquidity, which may affect the country's ability to finance current account deficits. The set of endogenous variables includes domestic interest rates, real government expenditure, real trade balance, and real effective exchange rates. We determine the optimal number of lags for each variable using Akaike's information criterion.

The SVAR model allows us to combine exposure (i.e., underlying shock volatility) with vulnerability (i.e., the estimated coefficients in each regression) to compute a variance decomposition of the dependent variable. The variance decomposition (also known as forecast error variance decomposition) helps us identify the amount of information that each variable contributes to the other variables in the system. In other words, it measures the share of the forecast error variance of each of the variables explained by exogenous shocks to the other variables.

Table 2.4 displays the medians of the real output growth variance decompositions across different regions after two years of the original shock.

TABLE 2.4. Variance Decomposition

Region	All Countries	Advanced Economies	Emerging Asia	Emerging Europe	Latin America and the Caribbean
<i>External factors</i>	24.0	27.9	16.8	23.1	20.3
Commodities TOT growth	10.5 (8.7)	10.7 (10.6)	8.5 (12.0)	10.1 (4.0)	11.2 (5.6)
Real interest rate (U.S.)	5.2 (6.7)	7.5 (7.0)	2.0 (2.3)	4.3 (7.6)	4.5 (3.4)
Output growth (U.S.)	8.3 (10.7)	9.7 (14.9)	6.3 (5.6)	8.7 (4.4)	4.6 (5.0)
<i>Domestic factors</i>	14.1	13.1	16.2	18.7	14.5
Real government consumption growth	4.7 (11.2)	4.2 (4.6)	2.6 (4.0)	7.6 (5.1)	6.2 (23.7)
Trade balance/GDP growth	3.0 (4.9)	3.0 (4.1)	3.0 (2.1)	3.4 (5.7)	2.5 (5.4)
Domestic real interest rate	4.4 (6.0)	3.9 (5.5)	5.1 (8.1)	6.5 (7.9)	4.1 (3.4)
Real effective exchange rate growth	2.0 (3.0)	2.0 (2.3)	5.5 (3.6)	1.2 (3.8)	1.7 (3.6)
<i>Persistence</i>	50.4 (20.3)	45.4 (20.2)	57.6 (22.7)	53.8 (18.6)	55.5 (20.7)

Note: See Appendix B for countries included in each region. Sources: Authors' estimations based on data from BIS, BOP-IMF, IFS, Penn World Tables, UN Comtrade, World Bank Commodity Price Data (Pinksheets), and WDI.

Four findings are worth noting. First, and in line with recent papers, we find that external factors explain a large share of the forecast error variance in all regions.²⁵ Moreover, this share is significantly larger than that of the combined domestic factors in all the regions. Emerging Asia seems to be the exception with the lowest share. This may be due to the trade policies put in place by many of those economies to promote their export led growth agenda. This idea is supported by the fact that global demand seems to be the most important external shock for Emerging Asia. Second, in LAC, not surprisingly, CTOT is the most relevant external risk factor explaining more than eleven percent of the predicted real output variance. Third, while the region generally suffers from the exposure to global liquidity, it is relatively well insulated from changes in global demand. Finally, output growth tends to be highly auto-correlated, as in previous literature. This is to be expected, because of potential omitted variables (including further lags).

Vulnerability to Power-Law Events

Another important source of external risk in the region is due to events characterized by distributions with fatter tails, where a single massive event can dominate the underlying moments of the sample distribution. Since the previous econometric analysis does not seem to be the right tool to fully capture the complex exposure and vulnerability of LAC to these types of risk, this section uses instead a series of simple but powerful descriptive metrics. Among all the potential candidates, two types of events characterized by power law distributions are the most prevalent in the region: natural disasters and sudden stops of capital inflows. This sub-section analyzes the exposure and vulnerability to these two types of risk.

It has been well documented that large and sudden reversals of private capital inflows may have important negative economic consequences for emerging markets.²⁶ Foreign capital flight can lead to large real depreciations and higher real interest rates that can worsen recessions and make the domestic financial system more fragile. Such capital inflow reversals can be relatively small and transitory or very large and persistent and are usually triggered by a sudden change of heart in international investors. This “change of heart” can originate from shifts in domestic economic conditions or, more often than not, from negative external shocks that could force a global portfolio rebalancing, an increase in overall risk perception by foreign investors, or generate a pure contagion effect.

We will define a sudden stop episode as occurring when portfolio investments and other investments' net incurrence of liabilities (as percentage of GDP) of the private sector decline below the average of the previous five years by at least 1.5 standard deviations (also of the previous five years). The exclusion window between episodes is one year. Private sector includes deposit-taking corporations (except central bank) and other sectors, such as nonfinancial corporations and other financial corporations.

²⁵ See Hnatkovska and Koehler-Geib (2018).

²⁶ See Edwards (2004) and Eichengreen and Gupta (2016).

TABLE 2.5. Vulnerability to Sudden Stops

Region	Total episodes	Average duration (in years)	Number of countries/Number of countries in regions (%)	Median of average real GDP growth 3 years before (%)	Median of average real GDP growth 3 years after (%)	Difference (in percentage points)
Advanced Economies	102	1.5	1.0	2.9	1.4	-1.5
Emerging Asia	82	1.2	0.9	4.7	3.7	-1.0
Emerging Europe	45	1.7	0.9	3.9	1.5	-2.4
Latin America and the Caribbean	119	1.5	0.9	3.3	1.7	-1.6
<i>Caribbean</i>	39	1.3	0.8	2.6	1.5	-1.1
<i>Central America</i>	30	1.4	1.0	4.3	1.7	-2.6
<i>South America and Mexico</i>	50	1.6	1.0	3.3	1.8	-1.5
Middle East and North Africa	87	1.3	1.0	4.4	3.5	-0.9
Sub-Saharan Africa	132	1.3	0.9	4.0	3.0	-1.0

Notes: See Appendix B for countries included in each region. Figures for LAC are aggregates of the three sub-regions. A sudden stop is defined as occurring when portfolio investments and other investments' net incurrence of liabilities (as percentage of GDP) of the private sector decline below the average of the previous five years by at least 1.5 standard deviations. The exclusion window between episodes is one year. Sources: Authors' computations based on data from BOP-IMF and WDI.

Given this definition, from Table 2.5, we find that the region is second only to Sub-Saharan Africa in the number of total episodes. Across LAC sub-regions, South American economies and Mexico are the ones suffering the longest reversals and the higher number of them. In terms of the economic effects of these events, the last column in Table 2.5 marks the median of the difference in output growth before and after each event. From this column, we see that growth in the median economy in the region was 1.6 percentage points higher before than after the reversal. This is a very large impact, second only to the one in Emerging Europe. In terms of sub-regions, Central American economies suffered the most severe consequences with a median fall of 2.6 percentage points, the largest for any region.

The information in Table 2.5 gives us an overview of the regions' relative exposure and vulnerability to sudden stops of private capital inflows. Unfortunately, LAC together with Sub-Saharan Africa are the regions with the highest number of recorded reversals. Moreover, these episodes tend to be long and cut deep into the regions' economic growth.

Another set of very important risks for the region comes from natural disasters. Natural disasters have resulted in significant economic and human losses for as long as humans have congregated in towns and cities. Catastrophic events have been a feature of life for millions of citizens in the region. Major recent catastrophic events – such as hurricanes Irma and Maria as well as last year's earthquakes in Mexico City and the south of the country – have brought the human and material cost of these crises to the forefront of public attention worldwide.

Table 2.6 describes LAC's exposure and vulnerability to natural disasters. We define natural disasters following the EM-DAT methodology, which requires at least one of the following criteria to be fulfilled: 10 or more people dead, 100 or more people affected, the declaration of a state of emergency, and/or a call for international assistance.

TABLE 2.6. Natural Disasters across Regions and Sub-Regions of LAC, 1960-2017

Region	Total natural disasters	Percentage	Natural disasters per million people per year	Deaths per million people per year	Damage per million people per year (USD millions)	Damage/GDP per year (%)
East Asia and Pacific	3,815	27.8	0.03	9	23.3	0.2
Europe and Central Asia	2,023	14.7	0.04	5	13.5	0.1
Latin America and the Caribbean	2,344	17.1	0.09	21	16.7	0.3
<i>Caribbean</i>	535	22.8	0.26	110	30.9	1.7
<i>Central America</i>	464	19.8	0.24	54	40.3	1.0
<i>South America and Mexico</i>	1,345	57.4	0.06	12	13.7	0.2
Middle East and North Africa	585	4.2	0.04	15	9.7	0.2
North America	1,012	7.4	0.06	1	67.7	0.2
South Asia	1,575	11.5	0.02	60	8.1	0.4
Sub-Saharan Africa	2,380	17.3	0.06	36	1.5	0.1

Notes: See Appendix B for countries included in each region. Figures for LAC are aggregates of the three sub-regions. Damage per 1,000,000 people was adjusted by purchasing power parity. Sources: Authors' computations based on data from EM-DAT, Penn World Tables, and WDI.

Under this broad definition – and with a total of 2,344 events – LAC experiences about 17 percent of all global natural disasters. Within the region, South America and Mexico suffered more than half of these events (57.4 percent). Of course, absolute terms may not be a good indicator of relative exposure since we are comparing regions of very different sizes. A way to make these figures comparable is to compute the number of disasters per million people per year. Once we do this, LAC becomes the region with the highest rate of disasters. LAC suffers almost 0.1 events per million people per year. Worse even are the ratios in the Caribbean and Central America sub-regions with 0.26 and 0.24 events per million people per year, respectively.

In terms of vulnerability, Table 2.6 offers statistics of the number of deaths due to natural disasters per million people per year. Here it is worth noting a clear heterogeneity across sub-regions in LAC. While the Caribbean ranks at the top of all regions in terms of casualties per million people per year, South America and Mexico seem to be in line with other emerging regions. Two additional measures of vulnerability are displayed at the end of Table 2.6. Looking at the latter, damage over GDP per year, we must highlight the strikingly high amount of damage suffered by the Caribbean and Central American sub-regions with 1.7 and 1 percent of GDP per year loss, entirely due to natural disasters. This is an order of magnitude higher than any other region in the globe.

Table 2.7 highlights the three most prominent types of natural disasters: earthquakes, floods, and storms. Looking at earthquakes in Panel A, it is worth stressing the large exposure to these events experienced by LAC. Not only does the region suffer a large number of events (198) but their intensity (6.49) is significantly higher than any other region in the world.²⁷ In terms of vulnerability, LAC again leads globally (together with East Asia and Pacific and MENA) in the number of deaths per million people per year and suffers considerable damage (as percentage of GDP). With regards to floods, LAC is the region with the most events per million people per year, and in terms of magnitude only

²⁷ As explained in previous sections, please note that the Richter scale is logarithmic so that a 6.6 earthquake is 1.4 times stronger than a 6.4 one.

lags behind North America. Finally, while not surprising, the news in terms of storms are possibly the worst, particularly for the Caribbean and Central America. These sub-regions unfortunately lead in terms of damage (as percentage of GDP); the Caribbean also does in magnitude. Damage from these storms costs the Caribbean and Central America an average of 1.68 and 0.44 percent of the sub-regions' GDP per year, respectively, a heavy burden for growth in the region.

TABLE 2.7. Main Natural Disasters across Regions and Sub-Regions of LAC, 1960-2017

PANEL A. Earthquakes

Region	Total natural disasters	Percentage	Magnitude (Richter scale)	Natural disasters per million people per year	Deaths per million people per year	Damage per million people per year (USD millions)	Damage/GDP per year (%)
East Asia and Pacific	403	35.5	6.38	0.004	6	5.9	0.09
Europe and Central Asia	232	20.4	5.85	0.005	1	4.0	0.03
Latin America and the Caribbean	198	17.4	6.49	0.008	14	6.0	0.08
<i>Caribbean</i>	10	5.1	6.86	0.005	94	8.3	0.05
<i>Central America</i>	50	25.3	6.25	0.029	30	17.3	0.50
<i>South America and Mexico</i>	138	69.7	6.56	0.007	6	5.1	0.10
Middle East and North Africa	125	11.0	5.84	0.009	14	5.7	0.09
North America	30	2.6	6.14	0.002	0	4.0	0.01
South Asia	106	9.3	6.47	0.001	2	0.8	0.03
Sub-Saharan Africa	43	3.8	6.30	0.001	0	0.0	0.00

PANEL B. Floods

Region	Total natural disasters	Percentage	Magnitude (in km ²)	Natural disasters per million people per year	Deaths per million people per year	Damage per million people per year (USD millions)	Damage/GDP per year (%)
East Asia and Pacific	1,178	24.9	66,034	0.010	1	9.8	0.07
Europe and Central Asia	688	14.5	46,400	0.014	0	4.9	0.03
Latin America and the Caribbean	890	18.8	99,913	0.032	2	3.3	0.05
<i>Caribbean</i>	145	16.3	10,522	0.069	3	0.7	0.02
<i>Central America</i>	172	19.3	11,830	0.087	2	3.4	0.08
<i>South America and Mexico</i>	573	64.4	124,884	0.025	2	3.6	0.06
Middle East and North Africa	275	5.8	90,265	0.018	1	2.3	0.05
North America	211	4.4	106,509	0.012	0	6.0	0.02
South Asia	648	13.7	70,965	0.009	3	5.2	0.24
Sub-Saharan Africa	848	17.9	59,576	0.021	1	0.4	0.03

PANEL C. Storms

Region	Total natural disasters	Percentage	Magnitude (in km/h)	Natural disasters per million people per year	Deaths per million people per year	Damage per million people per year (USD millions)	Damage/GDP per year (%)
East Asia and Pacific	1,443	37.9	162.3	0.013	2	4.8	0.06
Europe and Central Asia	491	12.9	141.2	0.010	0	2.7	0.02
Latin America and the Caribbean	598	15.7	171.6	0.022	2	4.8	0.10
<i>Caribbean</i>	311	52.0	186.8	0.156	11	21.7	1.68
<i>Central America</i>	102	17.1	169.5	0.052	19	18.4	0.44
<i>South America and Mexico</i>	185	30.9	152.1	0.008	0	2.2	0.03
Middle East and North Africa	66	1.7	116.1	0.004	0	0.7	0.01
North America	604	15.8	167.9	0.035	1	50.1	0.12
South Asia	372	9.8	122.6	0.006	14	1.7	0.09
Sub-Saharan Africa	237	6.2	176.2	0.007	0	0.5	0.03

Notes: See Appendix B for countries included in each region. Figures for LAC are aggregates of the three sub-regions. Damage per 1,000,000 people was adjusted by purchasing power parity. Average magnitude, deaths, and damage for all three panels was computed for a sub-sample of natural disasters due to data availability. Sources: Authors' computations based on data from EM-DAT, Penn World Tables, and World Development Indicators.

To sum up, LAC is extremely exposed and vulnerable to a large set of natural disasters. Specifically, earthquakes and floods ravage entire regions in Central and South America while hurricanes devastate the Caribbean. In terms of human losses and economic damage, the region is among the most vulnerable of the globe pointing to either a concentration of population around the areas where these events take place and/or a lack of full-fledged risk management practices.

Chapter 3:

Risk in Theory

Introduction

Chapter 2 introduced the main concepts related to known unknowns and unknown unknowns. This distinction is critical because known unknowns have, in principle, known distributions, which provide us with important information such as the mean and the standard deviation. Hence, while we may not know what a particular draw from such a distribution may look like (i.e., whether a person chosen at random will be tall or short), we know that 99.7 percent of the population’s height lies between 160.5 and 184.9 cm (Figure 2.2). The normal distribution is particularly useful because it is fully characterized by its first two moments (i.e., mean and standard deviation). In other words, with this information at hand, we can compute any probability related to that particular distribution. This is not the case for unknown unknowns (black swans) since we do not know their distribution (or even if they have one).

Why is the knowledge of the underlying distribution critical for economics and finance? The reason is that risky events that follow a known distribution can be insured. As Lewis (2007) puts it,

Geico sells auto insurance to more than seven million Americans. No individual car accident can be foreseen, obviously, but the total number of accidents over a large population is amazingly predictable. The company knows from past experience what percentage of the drivers it insures will file claims and how much those claims will cost.

For risks characterized by thin-tail distributions, a particularly helpful way to obtain market insurance is through financial derivatives. Specifically, we could use a call (put) option which gives the buyer the right to buy (sell) an underlying security at a given price at a determined date. This, for example, can help protect a commodity importer (exporter) from large swings in the market price of the underlying commodity. Under the right framework, these derivative contracts can potentially “complete” the market (i.e., can provide a price for each state of nature). For these markets to be effective, a substantial amount of information about the behavior of the underlying asset needs to be known ex-ante. An increase in the unpredictability of the distribution of the underlying variable will carry premiums in the derivative markets and can lead to incomplete markets.

For risks characterized by fat-tail distributions, the lack of information about future realizations immediately imposes an incomplete markets framework in terms of insurance. An interesting example is given by the limited catastrophe insurance offered by the market through catastrophe bonds (cat bonds). These bonds have the potential to provide immediate but partial relief to areas affected by natural disasters. The inability to secure full insurance for such major events highlights the need of other ex-ante strategies like building resilience and precautionary saving as well as securing ex-post access to much needed resources.

This chapter focuses on these two very different types of risk pricing. Since the available market pricing of both derivatives and catastrophe insurance seems to heavily rely on partial equilibrium frameworks, we will develop two general equilibrium models that help us better understand how insurance pricing depends on factors such as risk aversion, power tail distributions, and correlation across events.

Hedging Risk with Financial Derivatives

Using derivative contracts to hedge price risk is not a new development.²⁸ As soon as humans started trading in an organized manner, they quickly understood how the volatile nature of the world around them affected their trading opportunities. Events outside their control could translate into wild movements in the asset or commodity prices they needed to trade in the future. More importantly, those changes could spell disaster for their livelihood. As early as two millennia before Christ, traders in the Tigris and Euphrates rivers region developed relatively complex forward contracts baked on clay tokens. These tokens contained marks representing the quantities and prices of certain commodities that would be traded at a future date. It was common among French merchants in medieval Europe to issue “fair letters” which acted as lines of credit. Forward contracts on commodities were issued for hundreds of years in Antwerp since the inception of its Bourse in 1515. The Dojima Rice Exchange in Japan issued future contracts against rice from 1730 to 1937.

At the beginning of the 20th century, authors like Nelson (1904) were already discussing key elements of modern option valuation theory like the call-put parity, but it was not until the 1970’s with the introduction of technological breakthroughs in computational power, new methodologies that simplified options valuation like the Black-Scholes-Merton formulation, and the inauguration in 1973 of the Chicago Board Options Exchange that derivatives gained widespread use beyond specialized traders and markets.²⁹ Moreover, ever since 1992, when the Chicago Mercantile Exchange launched electronic option trading thus increasing liquidity and reducing transaction costs, the markets for these instruments have boomed.

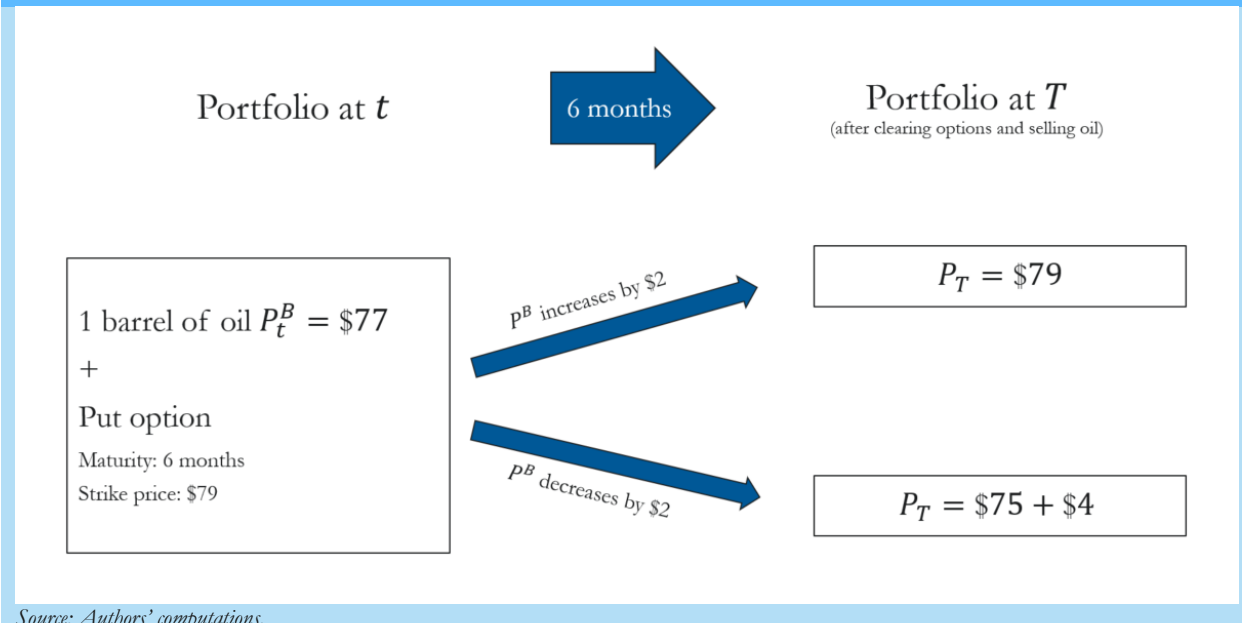
Simple Textbook Approach to Option Valuation Theory

A textbook example of how to price an option can be easily derived from a partial equilibrium story where we try to “eliminate” the price risk of an asset.³⁰ To make things even simpler, suppose that the price of the underlying asset can only go up or down by some amount in the future. In this simple setting, finding the value of the option that would allow us to completely hedge the price risk in this one-step binomial model only requires a simple no-arbitrage argument.

²⁸ See, for example, Poitras (2009) and Weber (2009).

²⁹ See Black and Scholes (1973) and Merton (1973).

³⁰ See, for example, Hull (2011).

FIGURE 3.1. Price of an Option: A Binomial Approach


Source: Authors' computations.

Consider an oil-exporting country that owns one barrel of oil priced at 77 dollars (as of August 31, 2018). As shown in Figure 3.1, the price of this barrel will either go up to 79 dollars or down to 75 dollars in six months.³¹ As an oil-exporting country, we are concerned about a decline in oil price so we can complete our portfolio with a put option, which would give us the right (but not the obligation) to sell a barrel of oil at a strike price of 79 dollars in six months. This means that in six months, our portfolio will be worth either 79 dollars if the price goes up (i.e., we do not exercise the put option) or 75 dollars + 4 dollars if the price goes down (i.e., we do exercise the put option). In the latter case, the option is worth 4 dollars because, aside from the single barrel of oil that the country owns, it would be able to buy one barrel of oil in the market at 75 dollars to immediately sell it at the strike price of 79 dollars to the option counterpart and, thus, obtain a net benefit of 4 dollars. A riskless portfolio means that the future value would be the same no matter the state of nature of the future oil price. This means that the values of the future portfolios under different prices will have to be the same, that is, 79 dollars = 75 dollars + 4 dollars. Buying a put option allows the country to build a riskless portfolio whose value would be 79 dollars regardless of the direction of the change in oil price.

Under no-arbitrage conditions, riskless portfolios must earn the risk-free interest rate. Suppose that the interest rate of the risk-free asset is 2 percent per annum. This means that the value of today's portfolio must be equal to the present discounted value (*PV*) of the portfolio six months hence, that is, 79 dollars. It follows that

³¹ Interestingly, notice that we do not need to assign probabilities to these events to obtain the price of the option. As explained by Cox *et al.* (1979), this counterintuitive feature of the option value is due to the assumption of risk neutral valuation, where all portfolios must earn the risk-free return. In this case, the probabilities are fully determined by the current stock price, the rate of increase and decrease of the stock price in the future, and the risk-free interest rate.

$$PV \text{ of } 79 = 79 * e^{-0.02 * (\frac{6}{12})} = 78.21.$$

If the value of today's portfolio adds up to 78.21 dollars and the barrel of oil is already worth 77 dollars, this means that the put option must be valued at 1.21 dollars. A value above 1.21 dollars would open the possibility of borrowing below the risk-free interest rate by shorting the portfolio.³² In contrast, a lesser value would imply a higher return than the risk-free interest rate asset. In either case, arbitrage (the pursuit of risk-free profit) would bring the price of the option back to 1.21 dollars.

While insightful, the continuous nature of asset markets makes the binomial example unrealistic. As a reference point, today's traders take the Black-Scholes Option Valuation Formula to price European options on a non-dividend-paying stock at a predetermined strike date. While the formal derivation of the Black-Scholes formula is mathematically complex, its intuition is relatively simple. Furthermore, we can use the binomial method to derive the Black-Scholes formula by allowing the number of steps (increases or decreases in the price of the underlying asset) to approach infinity (Cox *et al.*, 1979).

The Black-Scholes formula gives us the following value for a call option:

$$C(P_0, t) = \underbrace{\frac{P_0}{\text{Today's Price}}}_{\text{GROSS RETURN}} * \underbrace{N(d_1)}_{\text{Probability}} - \underbrace{\frac{Ke^{-r(T-t)}}{\text{PV of Strike Price}}}_{\text{COST}} * \underbrace{N(d_2)}_{\text{Probability}},$$

where $N(\text{z-score})$ is a standard normal with a z-score = $\frac{x-\mu}{\sigma}$,

$$d_1 = \frac{\underbrace{\ln\left(\frac{P_0}{K}\right)}_{\text{Value above strike price (x)}} + \underbrace{\left(r + \frac{\sigma^2}{2}\right)(T-t)}_{\text{risk free asset + spread over time (\mu)}}}{\underbrace{\sigma\sqrt{T-t}}_{\text{Volatility over time (\sigma)}}},$$

and

$$d_2 = d_1 - \sigma\sqrt{(T-t)}.$$

Intuitively, the Black-Scholes formula calculates the net return of the call option for an investor. Suppose, for the sake of argument, that the investor will find it advantageous to exercise his/her option with certainty (i.e., $N(d)$, which is the probability that the future market price will be above the strike price, is roughly equal to one).³³ Hence, the investor could buy his/her asset at the *PV* of the strike price (i.e., the cost) and sell it for today's market price, P_0 , (i.e., the gross return). The investor would thus be making a profit (i.e., the call would have a positive value or net return).

³² In other words, we would "sell" the portfolio effectively borrowing at a rate below the risk-free interest rate. This represents an arbitrage opportunity since we can always invest the borrowed amount in the risk-free asset. The spread would be risk-free profit.

³³ d_1 measures the excess of the future price over the strike price in terms of standard deviations. d_2 has a similar interpretation.

Using the Black-Scholes formulation to Price a Call Option

As discussed in Chapter 2, purchasing a call option may enable a country to insure itself against, say, unexpectedly high oil prices. In contrast to the example above, consider now an oil-importing country and that the price of oil is also 77 dollars per barrel. In this case, you are concerned that oil may continue to rise over the next 6 months. You would like to insure yourself against this possibility. One way of achieving this is to buy a call option that allows you to buy oil in the future at a given price. For example, you could buy a call option that gives you the right to buy oil at 80 dollars a barrel 6 months from now (March 31, 2019). In this example, 80 is the strike price.

Using the Black-Scholes formula (with real interest rate of 2 percent and annualized volatility of 10 percent), we get that the price of this call option would be 1.27 dollars.³⁴ In other words, you would have to pay 1.27 dollars for the right (but not the obligation) to purchase a barrel of oil at 80 dollars six months from now.

Intuitively, the price of the call option should be higher:

- the larger the time to maturity because it becomes more likely that the price of oil may surpass 80 dollars. Indeed, if we input a time to maturity of one year (compared to six months), the price increases from 1.27 to 2.44 dollars.
- the larger is the volatility of the oil price since this also makes it more likely that the price of oil may surpass 80 dollars. Indeed, if we input a volatility of 20 percent (compared to 10 percent), the price increases from 1.27 to 3.38 dollars.
- the lower is the strike price because it becomes more likely that you will choose to exercise the option. Indeed, if we input a strike price of 79 dollars (compared to 80), the price increases from 1.27 to 1.64 dollars.
- the higher the real risk-free interest rate. This increase is due to the fact that the risk-free interest rate is the opportunity cost of investing in other financial instruments such as stocks. All else equal, the higher the interest rate, the costlier to borrow to buy the stock, which means that the demand for the option would increase, and thus its price. Indeed, if we input a real interest rate of 5 percent (compared to 2 percent), the price increases from 1.27 to 1.71 dollars.
- the higher is today's oil price because it makes more likely that the strike price will be reached in six months. Indeed, if we input a current oil price of 78 dollars, the price increases from 1.27 to 1.67 dollars.

Weaknesses of the Black-Scholes Model

Given its simplicity and flexibility to accommodate alternative scenarios (like introducing dividends into the picture), the Black-Scholes model became a staple in the trading pits. However, several critics,

³⁴ You can use the online Black-Scholes calculator available at <https://www.mystockoptions.com/black-scholes.cfm>.

chief among them Nassim Taleb (2007), have argued that the Black-Scholes model is fragile to fat tail events due to the assumption that the shocks to the underlying asset follow a normal distribution.³⁵ This is a crucial point since, as seen in Chapter 2, the Black-Scholes formula is better suited to price insurance to protect against Type I risks than Type II.

In reality, while the Black-Scholes formula is still taught in all the finance textbooks and used as a reference point by option traders, there is a clear gap between the predictions of the Black-Scholes model and the actual pricing observed in the market. A simple proof of these large deviations from the Black-Scholes model comes from its assumption of a constant volatility of the underlying asset for different strike prices. This key assumption of the model is heavily contradicted by actual market data, since implied volatility of observed prices varies widely for different strike prices. Moreover, this increased volatility is symmetric relative to the point where the strike price equals the current price (and is typically referred to as “volatility smiles”). This means that an option whose strike price is further away, above or below, from the assumed underlying asset price is sold with a significant premium over the Black-Scholes predicted price. Volatility smiles seem to be due to traders’ adjustments to potential fat-tail events. The fact that volatility smiles seem to increase (i.e., premiums grow) after large shocks appears to support this hypothesis.

Insights on Option Pricing from a General Equilibrium Model

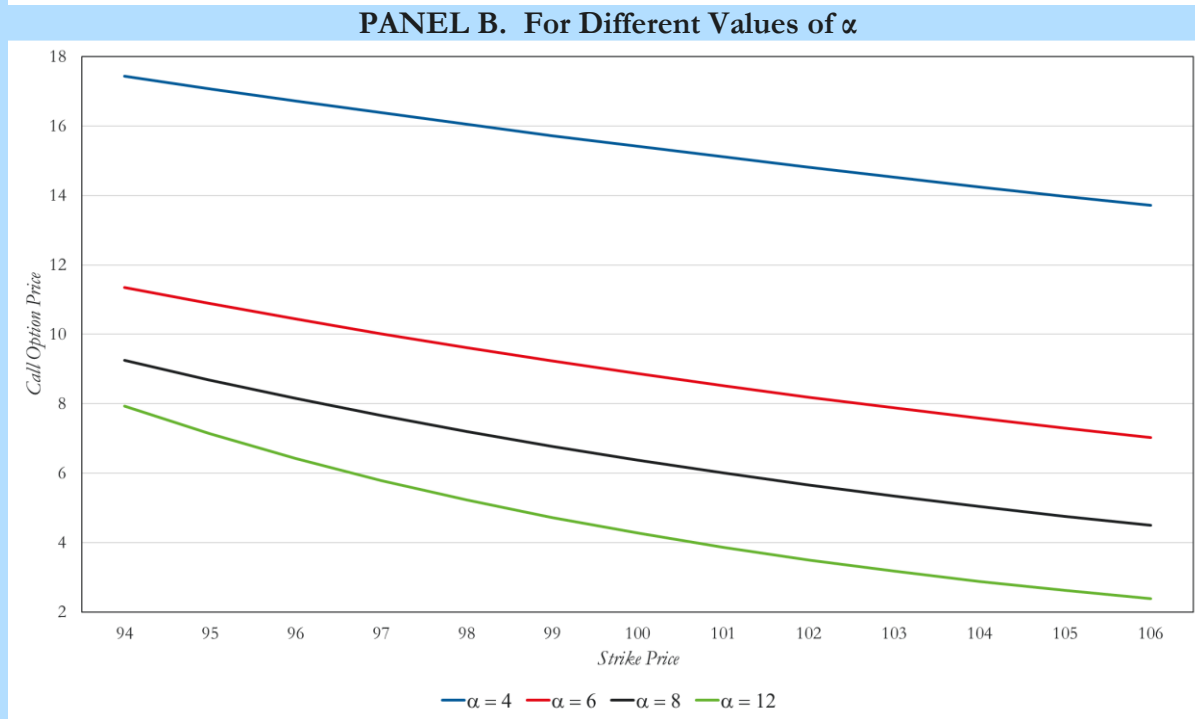
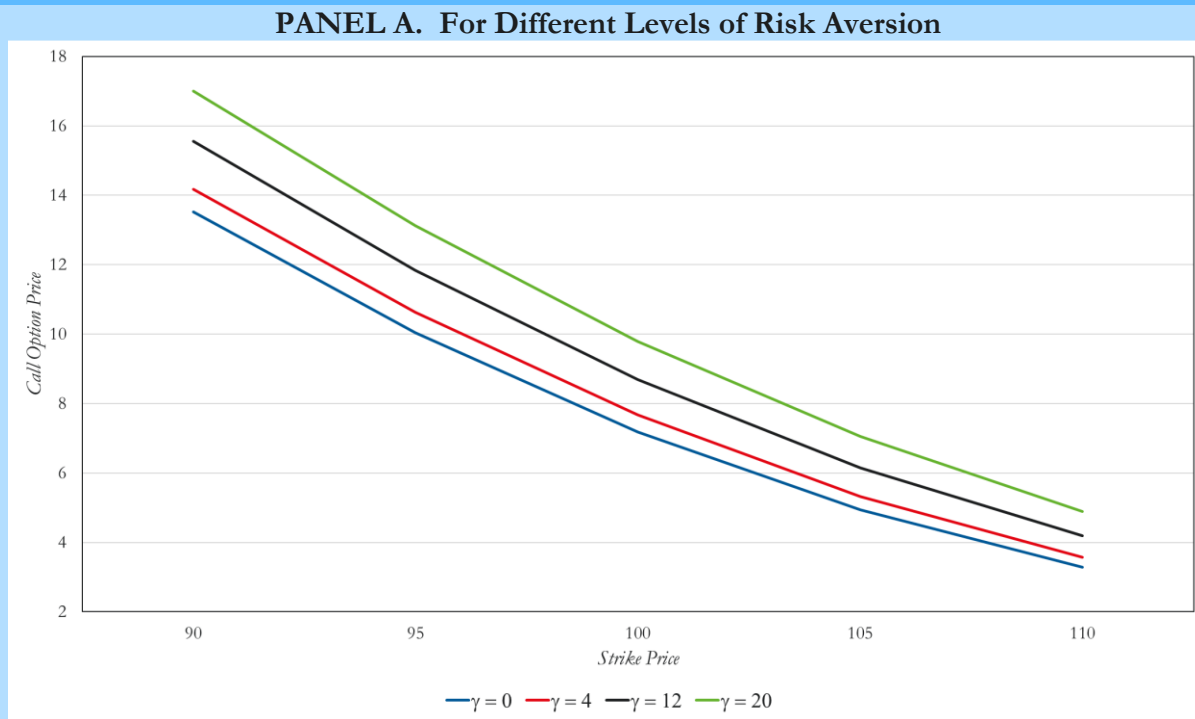
Gaining a deeper understanding of the puzzle of volatility smiles is difficult given the partial equilibrium nature of the Black-Scholes formula. This section addresses this limitation by deriving the Black-Scholes pricing equation from a general equilibrium model. This model enables us to show that volatility smiles may be explained by factors such as risk aversion or by traders accounting for the possibility of facing fatter tails than those predicted by a normal distribution.

Our general equilibrium model is based on the Lucas (1978) asset pricing model. We use this elegant model to price an asset that is defined as a claim on a stream of prospective payments. The intuitive way to think about this asset is in the context of a productive unit being a “tree” that bears fruit. Based on this idea, a “Lucas tree” is a claim on the consumption endowment and the solution to the model allows us to price such a claim.

The model is based on a closed, two-period, pure exchange economy with a risk-averse representative consumer.³⁶ Here, pure exchange means that all endowments are exogenous. Assuming identical endowments and preferences across consumers means that prices will adjust to neutralize any incentive to trade. Finally, we assume a known endowment in the first period and a stochastic one in the second. Without loss of generality, these assumptions make it relatively easy to compute competitive equilibrium prices.

³⁵ See also Haug and Taleb (2008).

³⁶ Appendix C spells out the model in detail. As a special case, we will have risk-neutral consumers.

FIGURE 3.2. Call Option Price as Function of Strike Price


Source: Authors' computations.

This model can replicate the Black-Scholes pricing solution for an “option” or claim to future consumption endowment assuming risk neutrality and using a normal distribution for the stochastic endowment in the second period. In line with the discussion above, as soon as we deviate from these two key assumptions, the option price will include a premium.

In this context, Figure 3.2, Panel A shows the price of an option as a function of the strike price for different degrees of risk aversion (γ). Intuitively, the higher the degree of risk aversion of consumers, the higher the price that they would be willing to pay to insure themselves. From this figure, we observe that as γ increases so does the price of the option for a given strike price. This premium seems to grow at a faster speed as we increase the household's sensitivity to risk (given by the difference between one line and the following).

Additionally, and for a power-law distribution, Figure 3.2. Panel B shows the price of an option as a function of the strike price for different values of α (recall from Chapter 2 that a lower α implies fatter tails). It can be shown that as we decrease α the premium increases exponentially. As α tends to one, the option cannot be priced. While assuming a power-law distribution may be an extreme assumption, recall from Chapter 2 that a number of asset and commodity prices have been shown to follow distributions with fat tails (like a q-Gaussian). This means that assuming a power-law distribution may be useful to understand the tail behavior of the underlying asset.

Figures 3.2 gives us two plausible explanations for the volatility smiles observed in market data. Our results seem to indicate that, going beyond the Black-Scholes formula, traders internalize factors like risk aversion and potential fat tail events in their pricing.

Insuring Against Natural Disasters

As we now know well, insuring against risks characterized by distributions with fat tails becomes more and more difficult as the tails become fatter. Some of the most relevant risks with fat tails for the region are natural disasters. As seen in Chapter 2, the intensity of these phenomena (and thus the potential damage they generate) tends to follow Pareto-type distributions with very fat tails. This means that while partial market insurance may be available, we will not be able to fully insure against these types of risk. Hence, we will need to complement insurance with other self-protective measures (such as building resilience and precautionary savings) as well as ex-post aid. Recently, a new type of insurance based on pooling resources from international capital markets has gained traction among countries in our region.

In the last three decades, insurance-linked securities (known as cat bonds) have helped transfer some risk of loss due to natural disasters from insurers to capital markets. These instruments are very attractive to both sides of the contract; the insured (which could be a group of individuals or a government) find a pool of money that can be accessed immediately when disaster strikes. On the other hand, these types of bonds are attractive to investors (insurers) because they are uncorrelated with portfolios based on stocks and traditional bonds. The way this instrument typically works is through a financial intermediary, a reinsurance company, or an investment bank, which issues a bond against a specific type of natural disaster in a specific geographical area, e.g. an earthquake in Chile. The proceeds from the sale are put into a collateral account. If there is no earthquake, investors are typically paid a coupon with a premium relative to investment-grade corporate bonds. If the earthquake occurs and the damage exceeds a pre-specified threshold, the collateral account is liquidated and investors cease to receive any additional interest and part or the whole principal amount.

A key element of these cat bonds are the trigger mechanisms involved to determine when the bond can be used to cover losses from a natural catastrophe. Trigger mechanisms can be divided into claim-based (i.e., indemnity or industry index) or parametric. The indemnity or the industry index trigger mechanisms would involve reimbursement to claims by insurers for their losses or part of the industry's losses from a predetermined point and up to the value of the bond. These mechanisms resemble traditional reinsurance schemes. The pure parametric, the parametric index, and the modeled loss trigger mechanisms use a set of defined physical parameters of the disaster directly or estimate a modelled loss to trigger the bond liquidation.

It is worth highlighting that in all cases, the cat bond only offers partial insurance up to the principal of the bond. Given the fat tails in the distribution of earthquake magnitude, no cat bond will be able to raise enough principal to cover for the worse case scenarios. While cat bonds have the potential to be extremely helpful providing much needed liquidity when disasters strike, they cannot be the only action taken by governments to protect its citizens against these events. Investment in resilience and self-insurance as well as preparing additional ex-post aid mechanisms are key factors in reducing natural disaster vulnerability across the region.

The structure of a cat bond, where there is a small but significant probability that part or all of the principal can be lost for investors, shares some similarities with defaultable bonds. Nevertheless, a major difference between the two is that cat bonds offer higher returns due to the difficulties in evaluating the random nature of the catastrophe process.³⁷

Valuation of a Cat Bond

Several recent articles tackle the issue of cat bond pricing. The key difficulty dealing with such pricing is the fact that the underlying process of the cat bond is driven by two distributions: (i) the probability of an event occurring, and (ii) the intensity of such event. Jointly, these distributions determine the probability of the bond being either paid in full to investors or being liquidated to help the insured. Baryshnikov *et al.* (2001) address the issue of the double distribution and present an arbitrage-free solution to the pricing of cat bonds using a compound doubly stochastic Poisson process. Burnecki and Kukla (2003) apply their results to calculate non-arbitrage prices of a zero-coupon and coupon cat bond.

Following Burnecki and Kukla (2003), we can price a simple zero-coupon cat bond using a doubly stochastic Poisson process $M_s (s \in [0, T])$ to measure the probability of occurrence of the natural disaster.³⁸ The intensity of this process is assumed to be a predictable process m_s . While, as discussed above, there are several ways to define the cat bond strike thresholds, for simplicity, we assume that the bond can be liquidated only if the accumulated losses L at time t are larger than some threshold D . The aggregate loss process is defined as $L_t = \sum_{i=1}^{M_t} X_i$ where X_i are independent and identically

³⁷ Kau and Keenan (1996) compare catastrophe triggers and defaults in a log-normal context.

³⁸ See Brémaud (1981).

distributed processes. Moreover, X and M are also independent. Under these assumptions, a zero-coupon cat bond paying a certain amount Z at maturity time T with a strike threshold of D will have a value for investors of

$$V_t = \mathbf{E} \left(\underbrace{Z_t e^{-r(t,T)}}_{\text{Present discounted value of future payment}} \underbrace{\left[1 - \int_t^T m_s [1 - F(D - L_s)] \mathbf{1}_{\{L_s < D\}} ds \right]}_{\text{Probability of not liquidating the bond}} \middle| \mathcal{F}_t \right),$$

where r is the risk-free interest rate and $F(\cdot)$ is a probability function of the strength of the natural disaster. As one may expect, increasing the time to maturity or decreasing the threshold level (thus increasing the probability that the cumulative loss surpasses the threshold) will decrease the value of the bond.

Also, if, as we believe, $F(\cdot)$ turns out to represent a Pareto-type distribution with fat tails, the fatter they are, the larger the probability that a tail event will generate losses big enough to exceed the threshold. This, of course, means that fatter tails will be associated with higher premiums and thus a lower present discounted value of the bond. If the tails are fat enough, the premiums could be so high that the market would disappear.

These models showcase again the general theme that more randomness will lead to less insurance. Cat bonds, while a very useful tool, will only be able to cover a relatively small amount of the potential risk involved in natural disasters.

Weaknesses of ad hoc Cat Bond Valuation

As shown in Härdle and Lopez Cabrera (2010), using modeled-index cat bonds to replicate the actual pricing of these instruments in the market seems to work well for a single country like Mexico. Nevertheless, these models represent a partial equilibrium at best and, more importantly, abstract from the potential importance of correlations between events over time.³⁹ This latter omission gains relevance as countries start to pool resources together in search of more effective risk sharing and thus, cheaper insurance (the recent cat bond issued by the World Bank on behalf of the four countries of the Pacific Alliance seems like a perfect example).

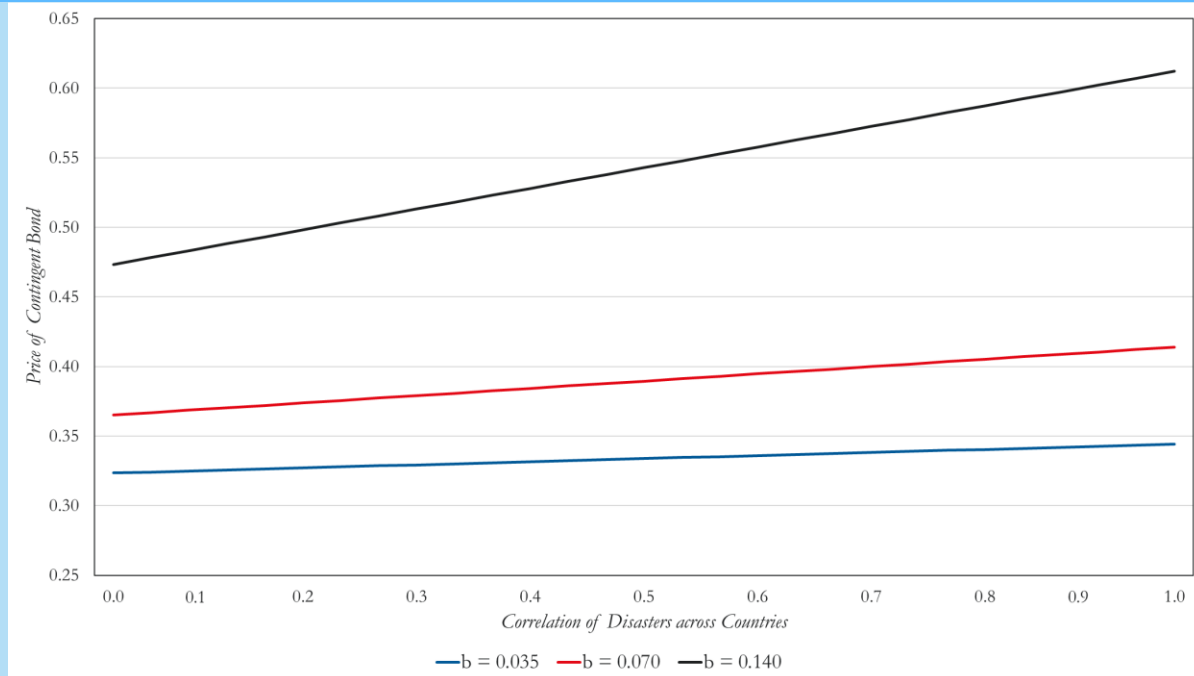
To highlight the key role of the cross-country correlation in the pricing of insurance, we now introduce a simple two-country, two-period model. The model features a deterministic income in period 1 and a stochastic income in period 2 where the only source of uncertainty are disaster-type shocks. For simplicity, only the frequency of shock occurrence is random and not its size. This assumption obscures the important corollary that fatter tails reduces the availability of market insurance. However, this result is already clear from the ad hoc valuation described above and this simplifying assumption allows us to highlight the role of the correlations across countries, something that was not present in the above analysis. The model assumes symmetry across countries and predicts full risk sharing in all states of nature. In other words, risk sharing and thus insurance pricing will be a function of the

³⁹ Recall that we assumed that X_i are independent events and also independent from M .

correlation of events across countries. As in our previous section, we leave the details of the model for Appendix D.

Figure 3.3 shows the relationship between the price of insurance and the event correlations across countries. As expected, the price increases as the correlation tends to one. The correlation elasticity of the insurance price seems to be closely associated to the size of the disaster shock (b). The larger the shock, the more important is the correlation.

FIGURE 3.3. Price of Contingent Bond for Different Sizes of the Natural Disaster



Source: Authors' computations.

Beyond Insurance

So far, the analysis of this chapter has focused on the role of insurance markets in dealing with risk. In particular, the chapter has offered important insights regarding some of the most pressing limitations of conventional theoretical frameworks.

When pricing options, conventional frameworks have typically been formulated using partial equilibrium analysis and assuming risk neutrality as well as normal distributions. Relying on more general equilibrium frameworks, we showed that option pricing is affected by the degree of risk aversion (which might increase in turbulent global times) and by the distribution (recall that as discussed in Chapter 2, normal distributions are the exception rather than the rule). Regarding this last issue, we have shown that as distribution tails become fatter, the price of the option grows exponentially, making insurance unfeasible. Moreover, if markets are incomplete (e.g., because there are no prices for every asset in every possible state of the world and/or there is no perfect information), then, other strategies, instruments, and policies arise as complementary mechanisms to cope with risk.

When it comes to cat bonds, pricing formulas have also been derived in the context of partial equilibrium frameworks and assuming single-country issuance. By developing a general equilibrium framework and considering a multi-country cat bond issuance (a two-country model is used without loss of generality), we showed the crucial role played by the correlation of catastrophes across countries.

One of the best-known responses to risk under incomplete markets are precautionary savings.⁴⁰ If one cannot insure against every possible state of nature, then precautionary saving constitutes an efficient policy to confront bad draws in the future. For example, as we will discuss further in Chapter 4, precautionary savings (to deal with commodity price fluctuations, earthquakes and hurricanes) and international reserves (to cope with sudden stops) are among the more typical. Naturally, the size of such precautionary savings increases (as a proportion of income) with the variance of risk and/or the fatness of tails. Consequently, the opportunity cost of precautionary savings (i.e., the cost of doing something else with those funds) can be large if a country wanted to protect against risk solely using precautionary savings. This is particularly the case in those types of risk characterized by fat tails (like earthquakes and sudden stops).

For this reason, multilateral organizations' contingency lines offer a desirable alternative that acts as a substitute for precautionary savings. Much like credit cards, contingency lines offer the use of readily available resources to countries in case of a realization of a bad shock. Therefore, they provide the ex-post funds in case needed, yet reducing the opportunity cost of holding large sums of funds in the form of precautionary savings. As will be discussed further in Chapter 4, contingency lines have become an increasingly important source of protection against risk. Last, but certainly not least, another way to protect against risk is to implement preventive measures. For example, in the case of earthquakes, the creation of anti-seismic building codes has proved to be an effective way of reducing earthquake damage. Similarly, financial regulation may help smoothing out capital flows. It is important to note that, while counterintuitive at first, in most cases it does not prove optimal to implement preventive measures aimed at completely eliminating the risk under consideration. The reason is that doing so would be, in most cases, too costly as resources could be productively used elsewhere. Hence, as the next chapter shows, in practice, most countries rely on ex-post measures and aid to cope with tail risks.

⁴⁰ See Végh (2013) for details.

Chapter 4:

Risk Management in Practice

Introduction

As discussed in Chapters 2 and 3, the types of risk faced by different countries are crucial in terms of how to best manage them. Chapter 3 showed how Type I risks, which involve events characterized by normal distributions, can be fully insured by the market by relying on options. Due to the presence of thin tails, options offer a convenient instrument to insure against this type of risk. Unfortunately, as discussed in Chapter 2, most economic events (e.g., commodity prices, capital flows, and financial asset values) and natural disasters (e.g., earthquakes and hurricanes) do not follow this type of distribution.⁴¹ Therefore – as analyzed in Chapter 3 – these events are insurable only as long as the distribution’s tails are not too fat. The fatter the tails, the less market insurance will be available (because the occurrence of a single “fat tail” event could bankrupt the insurer). In such a case, the use of complementary risk management tools proves essential, including (i) preventive measures aimed at reducing the exposure to risk, (ii) precautionary/stabilization funds such as commodity-based sovereign wealth funds, natural disasters funds, and international reserves, (iii) contingency lines such as the IMF’s Flexible Credit Line and the World Bank’s Deferred Drawdown Option (DDO, added to many loans), and (iv) ex-post aid.⁴² Ex-post aid together with strong economic and institutional foundations are also critical in the aftermath of black swans to deal with such unpredictable and typically devastating events.

Table 4.1 characterizes the policy menu available to countries to manage risk and provides some examples that will be discussed in more detail later in the chapter.⁴³ Based on Chapter 2, Table 4.1 links the types of risk to the most common and effective ways to confront them.⁴⁴ Notice that Table 4.1 is not intended to provide a comprehensive list of all available instruments, strategies, and policies available but rather to illustrate the most common. As is clear from Table 4.1., the set of instruments, strategies, and policies comprises multilateral, market-based, and government solutions.⁴⁵

⁴¹ The frequency of natural disasters has been increasing in recent years. Organizations, such as Intergovernmental Panel on Climate Change, have stressed the impact of climate change on natural disasters. In this respect, the World Bank has developed different programs to mitigate the effects of climate change (see World Bank, 2016a).

⁴² While one could argue that ex-post aid is not, strictly speaking, a risk management tool because it is not aimed at curbing ex-ante risk but rather deal ex-post with adverse effects, we still include it as part of the set of risk management tools due to its crucial practical relevance in terms of dealing with the effects of risk.

⁴³ See Perry (2009) for a review of how countries coped with volatility in the aftermath of the Global Financial Crisis.

⁴⁴ For a normative approach on the use of financial instruments in a risk management contest, see Clarke *et al.* (2016).

⁴⁵ The role of the private sector in the context of risk management in developing countries is discussed in World Bank (2013).

TABLE 4.1. Risk Management Tools: A Policy Menu

	Known Unknowns				Unknown Unknowns
	Type I	Type II			Black Swans
Events/ Characterization	Rainfall (Droughts)	Commodity Prices	Earthquakes and Hurricanes	Sudden Stops	Unpredictable and Typically Large
Preventive Measures to Reduce Exposure to Risk	Monitoring and Warning, Regulation, and Infrastructure Development	Economic Diversification	Monitoring and Warning, Regulation, and Infrastructure Development	Stronger Macroeconomic and Financial Frameworks	No Risk Management Tools (Need to Rely on Ex-Post Aid, Strong Institutions, Resilience, and Knowledge)
Insurance	Hedging/Options (e.g., India, Mexico, and Uruguay)	Hedging/Options (e.g., Mexico and Uruguay)	Catastrophe Bonds (PA Cat Bond) and CCRIF-CA (Caribbean and CA)		
Contingency Lines			Cat DDOs	FCL (IMF) and DDOs (WB)	
Precautionary/ Stabilization Funds		Commodity-Based Sovereign Stabilization Funds (e.g., Chile)	Fonden (Mexico)	International Reserves	
Ex-Post Aid			Reconstruction Aid	Mainly IMF Stand-By Arrangement	

Source: Authors' elaboration.

The following sections review some of the most common and effective examples of the use of these instruments for each type of risk event.

Type I Risks

As discussed in Chapter 2, Type I risks involve events characterized by normal distributions. These events can thus be fully insured by the market by relying on options (e.g., a call or a put). Furthermore, familiar pricing formulas such as the famous Black-Scholes formula provide (subject to some limitations discussed in Chapter 3) a useful benchmark when it comes to protecting against this type of risk. Due to the presence of thin tails (i.e., extreme events are very rare), market options offer a convenient instrument to insure against these moderate and well-defined types of risk.

Insurance

As discussed in Chapter 2, a typical example of Type I risk is provided by certain weather-related phenomena including, for example, the case of rainfall in Uruguay. Rainfall in Uruguay is very important for many factors, including the production of energy for households and businesses. State-owned Uruguayan hydroelectric power plants provide about 60 percent of total energy produced in

Uruguay. When the country faces a drought, the government is then forced to import more oil to produce energy to compensate for this shortage. For example, in 2008, when rainfall was about one third less than usual, imports of oil increased by about 25 percent relative to the typical year. To insure against this chronic and costly risk, and with technical help of the World Bank, the Uruguayan government issued in 2014 a rainfall call option based on a rainfall index as a strike price and barrels of oil as the underlying asset. The Uruguayan rainfall option started in January 2014 and ended in June 2015 (the government did not exercise the option).

Excessive rain and droughts can also have large harmful effects in low income countries that depend heavily on agriculture, especially in countries with small family farms and a subsistence-level of production (World Bank, 2013). In these circumstances, a severe drought could, for example, cause large famines. Indeed, Ethiopia and Somalia suffered one of the worst famines caused by severe droughts in the early 1980's, which killed about 2 percent of their populations (to put this figure into context, it would be equivalent to the death of 7 million people in the United States today). To cope with the devastating effects of excessive rains and droughts, and in countries where weather insurance markets might not be already present, the World Bank has helped develop different weather indices which, in turn, are used to issue options. Relying on these indices, the World Bank together with domestic institutions have offered for some time insurance to farmers in India and Mexico to help them cope with droughts. As explained by Giné *et al.* (2010, p. 10), in the case of India,

the policy pays zero if accumulated rainfall during the phase exceeds an upper threshold, or strike price, which in this case is 100 mm. Otherwise, the policy pays 15 rupees for each mm of rainfall deficiency relative to the strike, until the lower threshold, or exit, is reached. If rainfall is below the exit value, the policy pays a fixed, higher indemnity of 2000 rupees. This exit level is meant to approximately correspond to crop failure. The choice of this nonlinear payout structure was in part made based on the use of crop models, in an attempt to maximize the correlation between rainfall deficiency and loss of crop yield.

Since the trigger of the insurance depends on rainfall, and not crop production, this instrument has the benefit of eliminating potential moral hazard problems.⁴⁶ In the case of Latin America, one of the most important cases of weather insurance for agriculture producers is managed by the state-unit *Agroasemex* in Mexico, which insures about 15 percent of the agriculture land.⁴⁷ To help insure against floods, the World Bank offers Thai farmers an insurance that includes rainfall and river's overflow parameters.⁴⁸

Preventive Measures

A critical component of risk management is to implement preventive measures to reduce exposure. In the case of flooding, permanent monitoring (e.g., by measuring the water levels of streams and

⁴⁶ See Barnett and Mahul (2007) for more details regarding the pros and cons of this insurance.

⁴⁷ See Fuchs and Wolff (2016) for details.

⁴⁸ See Lotsch *et al.* (2010) for more details.

rivers), flood warning centers and systems, zoning and construction regulations (e.g., banning building and settling in areas identified as risky zones), and developing infrastructure that eliminates or limits floods and protects the population (e.g., improving drainage, especially in cities, building dams and levees, building canals, and harvesting rain water) are, among other policies, important in reducing the exposure to flooding.

As an example, Greater Buenos Aires (i.e., the City of Buenos Aires and its suburbs) used to regularly have floods. The last big flood of 2013 directly affected 350,000 people (about 3 percent of total population in the area). In 2016, the City of Buenos Aires' Government, supported by the World Bank, started a new project to improve the drainage system in the Maldonado and Vega basins, the main sources of flood risk in the Greater Buenos Aires area. This project will reduce the risk of floods and avoid human and material losses.⁴⁹

In terms of droughts, Central American countries, such as El Salvador, have been systematically affected. To reduce the exposure to this type of risk, the World Bank and the government of El Salvador started a joint project in 2015, which is expected to benefit approximately 2,000 people, by improving the system of irrigation and reforesting rural areas.⁵⁰

Type II Risks

As discussed in Chapter 2, Type II risks involve events characterized by fat tail distributions including (i) the q-Gaussian, which belongs to a family of distributions with bell shape but fatter tails than the normal distribution (see Figure 2.7, Panels A and B for Dow Jones and oil price changes, respectively) and (ii) the power-law distribution, which is highly skewed, indicating that while the bulk of the distribution is concentrated around small values, there is a fat tail (see Panel A in Figures 2.5 and 2.6 for earthquakes and sudden stops, respectively).⁵¹

q-Gaussian Distributions

As discussed in Chapter 2, a good example of a q-Gaussian distribution is fluctuations in commodity prices, like the price of oil (see Figure 2.7, Panel B). In fact, as pointed out in Chapter 2, the LAC region is exposed about three-times as much to terms-of-trade risk than advanced economies. Naturally, oil price fluctuations involve risk for both oil producers and net exporters (like Mexico) as well as for oil net importers (like Uruguay). To deal with this type of risk, countries have increasingly started to insure themselves, often with the technical assistance and/or intermediation of the World

⁴⁹ See World Bank (2015b).

⁵⁰ See World Bank (2016b).

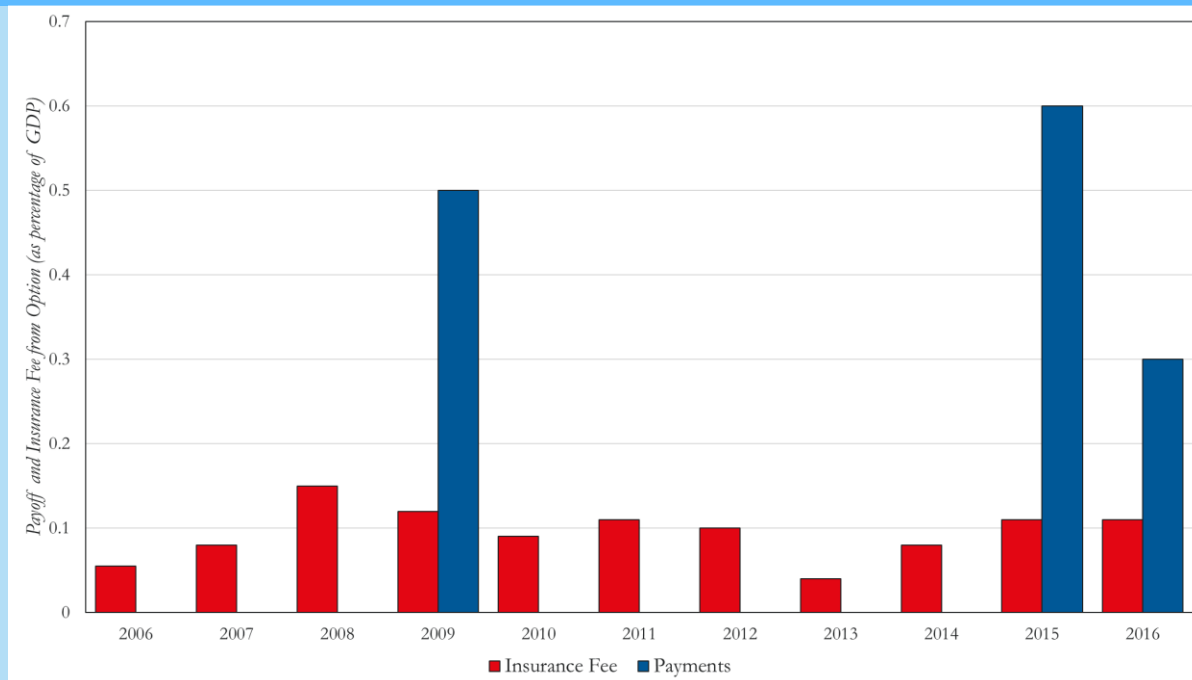
⁵¹ While we use the q-Gaussian and the Power-Law as two opposing examples of distributions with fat tails, there is a full family of distributions between these two that we abstract from (and would fall outside the scope of this report) to keep the discussion focused.

Bank, in addition to building precautionary/stabilization funds to reduce the exposure to commodity price fluctuations.

Insurance

The archetypal example is the Mexican oil hedge, which is the largest oil hedge in the world.⁵² Specifically, Mexico’s Finance Ministry buys put options that give Mexico the right to sell oil at a predetermined future price (which will be exercised if the future price is below the strike price). Since 2001 Mexico has spent, on average, about 0.1 percent of GDP every year using this option. Mexico has exercised this option only in 2009, 2015, and 2016 with payments representing 0.5, 0.6, and 0.3 percent of GDP, respectively (see Figure 4.1).

FIGURE 4.1. Mexican Oil Hedge



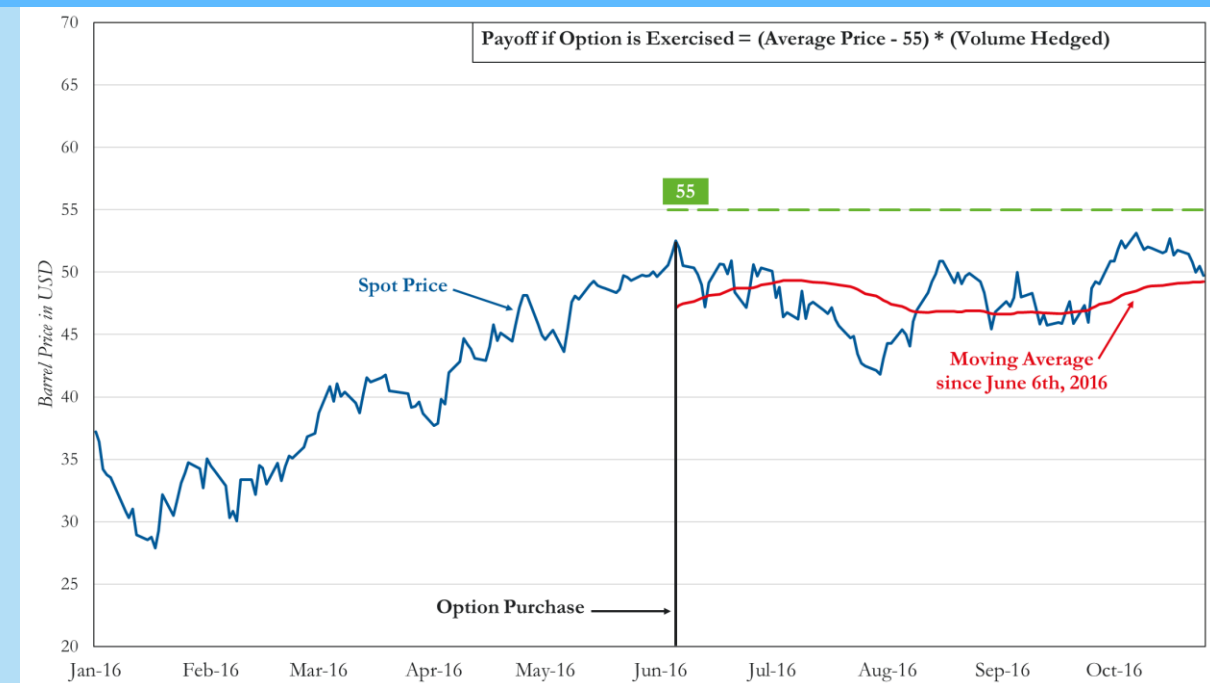
Sources: Auditoría Superior Federal, INEGI, and Ma and Valencia (2018).

In other cases, like the Uruguayan oil hedge in 2016, the World Bank has played a key role as an intermediary between the government and financial markets. Specifically, the Uruguayan government signed a call option contract with the World Bank, in effect from June 2016 to June 2017, for 6 million barrels of oil (around 50 percent of total barrels imported in 2016) at a strike price of 55 dollars per barrel.⁵³ Once the call option contract with the World Bank was finalized, these options were sold by the World Bank to a group of private banks. As illustrated in Figure 4.2, the price of oil remained below the strike price and the call option was not exercised.

⁵² See Bloomberg (2018).

⁵³ See World Bank (2016c).

FIGURE 4.2. Uruguayan Oil Hedge



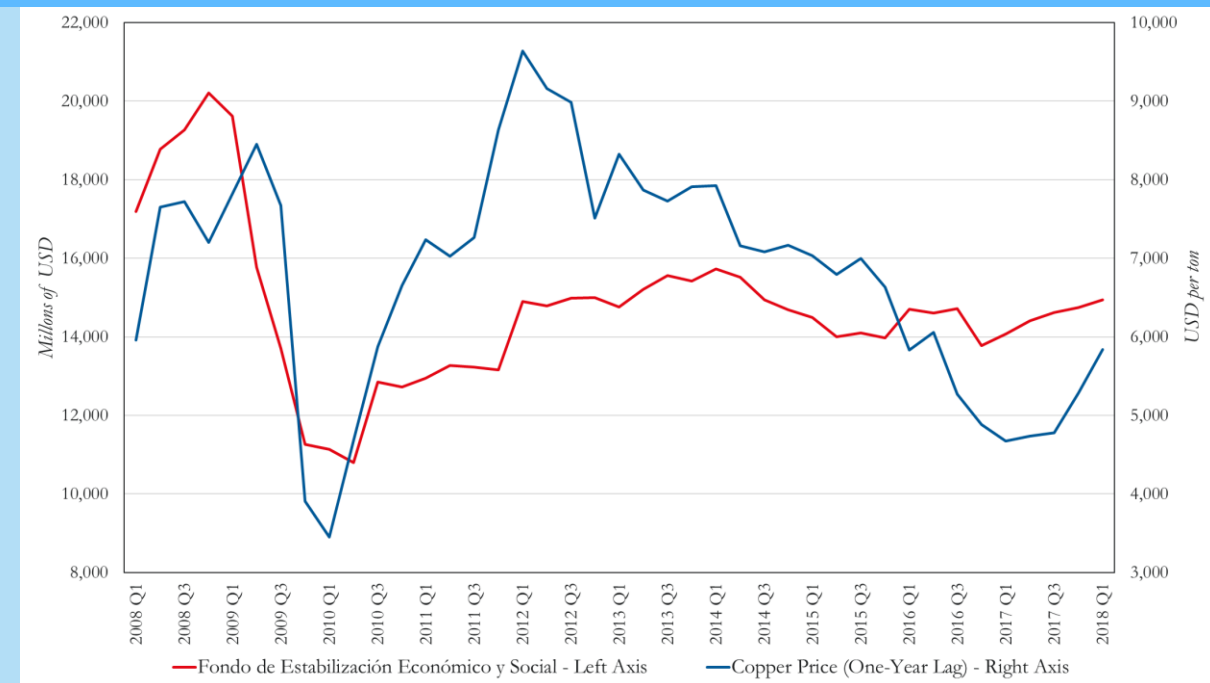
Sources: Bloomberg and World Bank.

Precautionary/Stabilization Funds

As discussed in Chapter 3, the presence of fat tails triggers, in practice, the use of complementary precautionary/stabilization instruments. Perhaps the most common are commodity-based sovereign wealth funds (which help protect against a fall in income for commodity exports). In turn, the best-known example of a commodity-based sovereign wealth fund in LAC is the Chilean *Fondo de Estabilización Económico y Social* (FEES), managed by the Central Bank of Chile. The FEES was created in 2007, based on a reform of the *Fondo de Estabilización de los Ingresos del Cobre* (FEC). Between 2001 and 2006, the FEC operated alongside the structural balance budget rule, which requires the government to save extraordinary income from temporarily higher copper prices and higher tax revenues generated by upswings in the business cycle.⁵⁴

To determine the savings (or dissavings) of the FEC, a reference price for copper was established, reflecting its long-run trend. Income above this price was deposited in the fund and income below it was transferred to the Treasury. The current objective of the FEES is to stabilize public spending by financing fiscal deficits resulting from lower income due to reductions in the price of copper, or more generally, because of a slowdown in the economy. Figure 4.3. shows that, indeed, the level of capitalization of the fund and the price of copper display a strong positive correlation (equal to 0.42), as expected.

⁵⁴ See Borensztein *et al.* (2013) for more details.

FIGURE 4.3. Chile's *Fondo de Estabilización Económico y Social*


Sources: Dirección de Presupuestos, Ministerio de Hacienda (Chile), and IMF.

Preventive Measures

Preventive measures to reduce exposure to risk could also play a significant role. Although easier said than done, economic diversification (moving away from the production and export of a few commodities), especially in small and very open economies, could increase the resilience to commodity price fluctuations. Since diversification essentially requires resources to be channeled away from sectors that already have a comparative advantage, diversification must not be pursued at all costs. In fact, as discussed in McIntyre *et al.* (2018), some viable strategies include diversification at the intensive margin (i.e., changing the share of existing commodities) and vertical diversification by entering higher value-added industries which, in turn, build resilience to commodity price fluctuations.

Power-Law Distributions: Managing Risk for Sudden Stops

Chapter 2 showed that sudden stops (i.e., sizeable and sharp private international capital inflow reversals) follow a power-law distribution. Sudden stops have hit the LAC region rather frequently (e.g., the 1980's debt crisis, the 1994 Mexican currency crisis, the 2001 Argentine crisis, and the aftermath of the global financial crisis of 2008-2009). In response, since the early 2000's, several countries in the region have improved their macro-fiscal framework relative to previous decades, thanks to better macroeconomic management over the business cycle, more central bank independence, the implementation of fiscal rules and, broadly speaking, better institutions.⁵⁵ As part

⁵⁵ See Végh *et al.* (2017a, b) and the references therein.

of these improvements, several countries have also implemented sizeable contingency lines with the IMF and the World Bank and have also accumulated large stocks of international reserves which, in turn, have helped them to reduce the exposure and negative economic effects of sudden stops. What follows are some of the main instruments, strategies, and policies implemented to deal with sudden stops.

Contingency Lines

The IMF's Flexible Credit Line (FCL). In 2009, after the global financial crisis, the IMF implemented the FCL, which assures pre-qualified countries (based on the strength of their policy frameworks) large and up-front access to IMF resources with no conditionality attached. This contingency line instrument was created in the context of reforming how the IMF lends resources to countries during a cash crunch, tailoring its lending instruments to the needs and circumstances of member countries. To date, two countries, Colombia and Mexico, have a FCL (Poland also had a FCL between 2009 and 2017).⁵⁶ While none of the two countries have so far drawn down on these lines, treating the FCL as a precautionary instrument, its mere existence should, in principle, deter sudden stops and other related risks. Figure 4.4. plots the series of FCL arrangements that Colombia, Mexico, and Poland have signed and their evolution during the last ten years.

The FCL works like a credit card with a pre-approved credit limit. If a person has a good credit history and a robust checking account at the bank, then he/she can probably access a large line of credit, which he/she may choose to use or not. By the same token, only countries with very strong economic fundamentals are eligible for an FCL. As stated by the IMF itself, the most important prerequisites are the following:

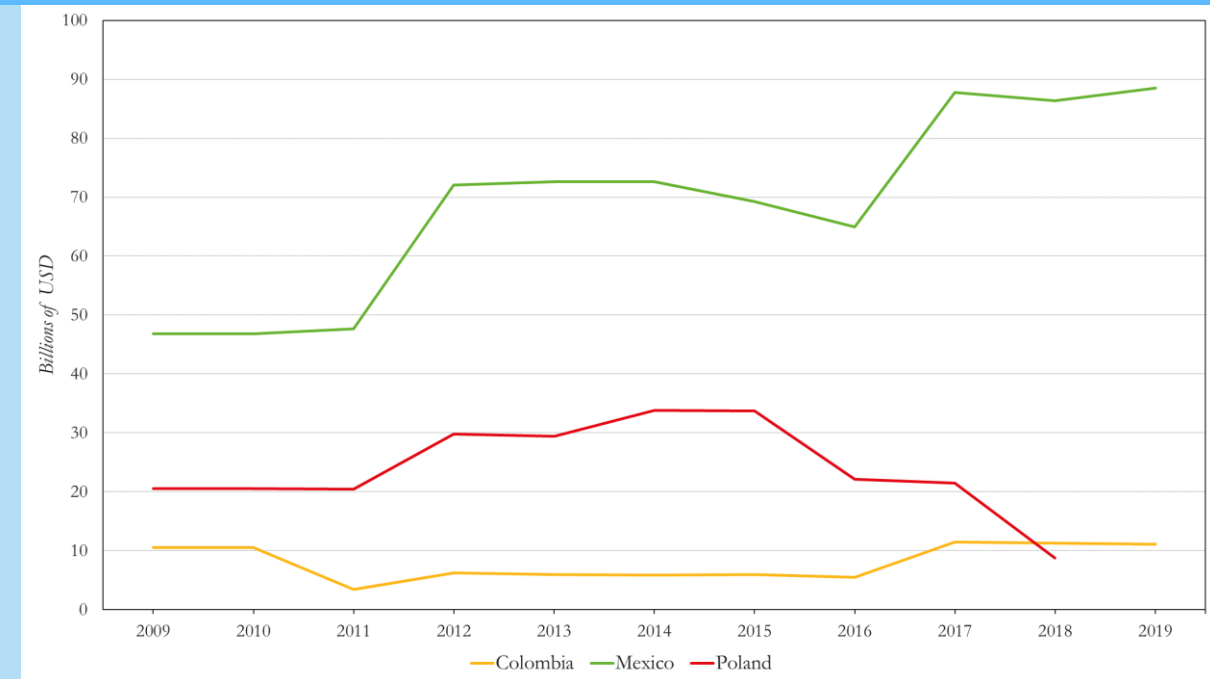
- a sustainable external position,
- a capital account financed mainly by private capital inflows,
- when the arrangement is requested on a precautionary basis, a reserve position which – notwithstanding potential balance of payments pressures that justify IMF assistance – remains relatively comfortable,
- sound public finances,
- low and stable inflation,
- data integrity and transparency,
- sound financial system and the absence of solvency problems that may threaten systemic stability.⁵⁷

If a country decides to draw on the FCL, repayment would take place over a 3-5 year period. The cost of borrowing under the FCL is the same as that under the Fund's traditional Stand-By Arrangement.

⁵⁶ For a detailed study on the determinants of countries demanding a FCL, see Essers and Ide (2017).

⁵⁷ See IMF (2018b).

FIGURE 4.4. IMF Flexible Credit Lines for Colombia, Mexico, and Poland



Source: IMF Press Releases.

Figure 4.4 plots the series of FCL arrangements that Colombia, Mexico, and Poland have signed and their evolution during the last ten years. We can see how this instrument quickly responded to the end-of-2016/beginning-of-2017 external political instability faced by Mexico, by increasing by 35 percent.

The World Bank's Deferred Drawdown Option (DDO) in Development Policy Operations. The Development Policy Financing (DPF) loans are one of the World Bank's main financing instruments.⁵⁸ Development Policy Operations (DPOs) seek to help countries achieve sustainable growth and poverty reduction through the support of a program of policy and institutional actions. This is provided in the form of non-earmarked loans, credits, grants or policy-based guarantees. In this context, the World Bank has come up with a key risk management provision, the DDO.

A DDO allows countries to postpone drawing down a World Bank loan for a defined drawdown period after the loan agreement has been declared effective. This option allows countries to use the funds whenever they deem it necessary – the drawdown is available upon the country's request – thus effectively constituting a contingent credit line. Between 2008 and 2017, 17 DPOs with DDO have been signed, 12 of them involving LAC countries. Table 4.2 shows the DPOs with DDO approved since 2008 to date. It is worth noting that the year before negotiating a much larger FCL with the IMF, Colombia and Mexico had already signed a DPO with DDO.

⁵⁸ Other World Bank instruments, such as the Investment Policy Financing, also include DDOs (for example, the 2014 IPF loan with DDO to Uruguay's National Development Corporation).

TABLE 4.2. DPOs with DDO Approved since 2008

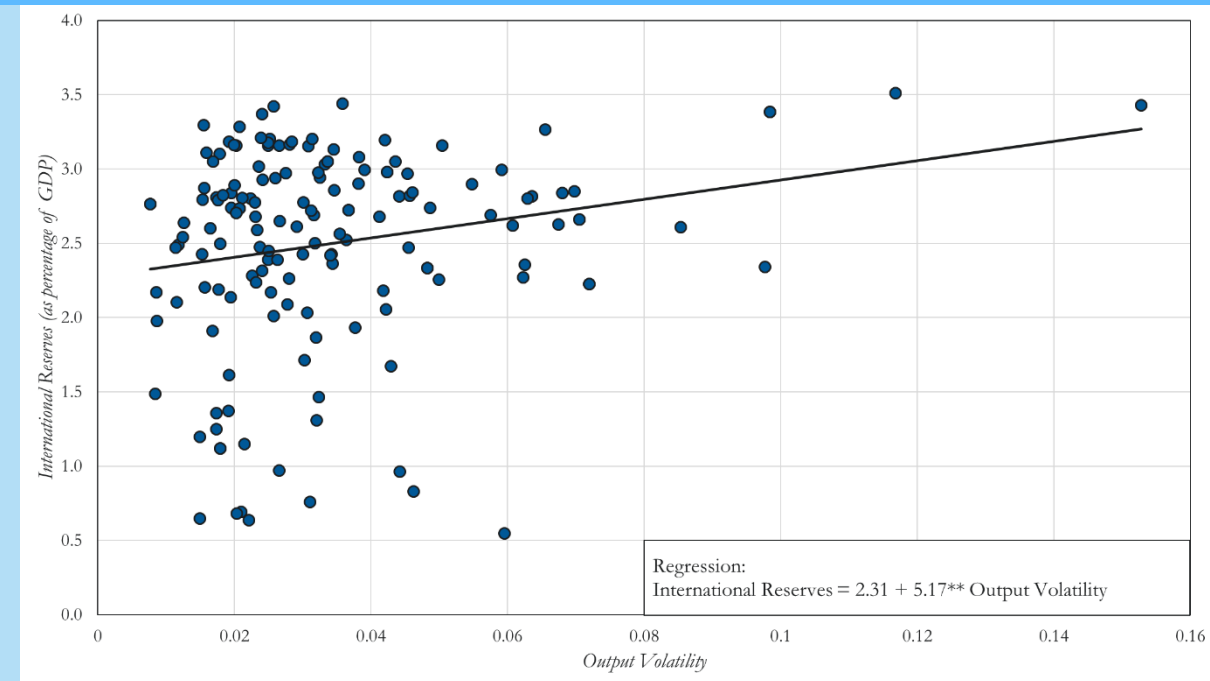
Country	Fiscal Year	Amount (millions of USD)	% Disbursed
1. Colombia	2008	550	100
2. Mexico	2008	501	100
3. Peru	2009	370	100
4. Bulgaria	2009	150	100
5. Peru	2009	330	100
6. Uruguay	2009	400	100
7. Peru	2009	330	100
8. Indonesia	2009	2,000	0
9. Mauritius	2009	100	100
10. Peru	2009	330	100
11. Costa Rica	2009	500	100
12. Uruguay	2012	260	0
13. Indonesia	2012	2,000	100
14. Romania	2012	1,333	100
15. Uruguay	2013	260	0
16. Paraguay	2015	100	33
17. Peru	2016	2,500	0
TOTAL		12,014	

Source: 2015 Development Policy Financing Retrospective (World Bank 2015a) and World Bank staff.

International Reserves

International reserves constitute one of the most common type of precautionary funds to deal with sudden and sharp reverse in capital flows, as it allows countries to smooth domestic absorption in response to sudden stops. The theoretical framework developed by Jeanne and Rancière (2006) provides estimates of the share of the observed stock of reserves that can be explained as a self-insurance against sudden stops. In line with this idea, Figure 4.5 shows, for a sample of 147 countries for the period 1999-2017, that countries with larger output volatility tend to hold more international reserves as a share of GDP.

FIGURE 4.5. International Reserves and Output Volatility



Source: Haver Analytics.

Preventive Measures

Preventive measures to reduce exposure to sudden stops play a vital role as well. Stronger macroeconomic and financial frameworks allow policymakers to respond more flexibly. Among the potential instrument and policies available, we should mention large international reserves (discussed above), allowing the exchange rate to float and thus act as a shock-absorber, macro-prudential policies, and capital controls (especially on inflows).

Ex-Post Aid

Ex-post aid mainly includes IMF Stand-By Arrangements that involve financial assistance to member countries in the event of a financial crisis. While the World Bank, CAF, and IDB have similar loans to help LAC countries, the IMF is, by design, the multilateral organization with the largest resources available to this end.

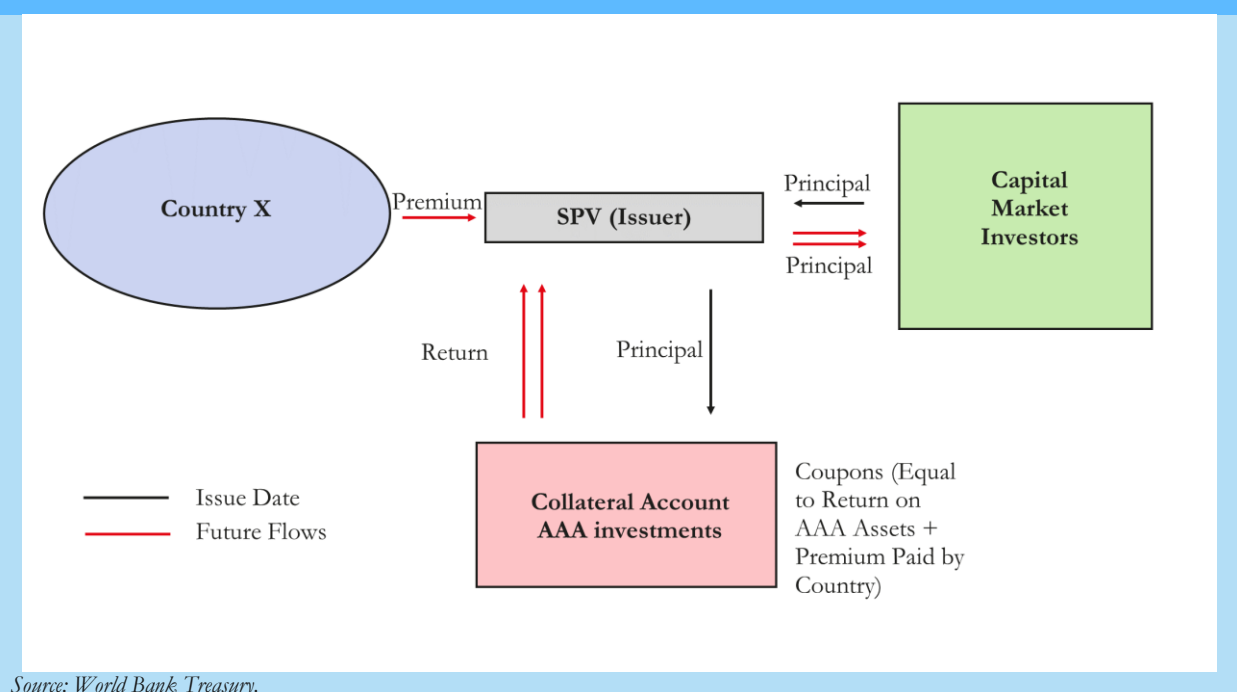
Power-Law Distributions: Managing Risk for Earthquakes and Hurricanes

Natural disasters are known to be a large source of risk, as they can lead to tremendous human and material losses. While predicting the time of occurrence is hard (especially for earthquakes), the broad geographical areas affected are readily identifiable due to seismic and wind patterns. For example, earthquakes are more likely to occur along the Andes and Mexico, and hurricanes are more prone to happen in the Caribbean and Central America. In light of these characteristics, countries often in conjunction with the World Bank, have developed different kinds of risk management instruments.

The Pacific Alliance Catastrophe Bond (PA Cat Bond)

Since the mid 2000's, some developing countries such as Mexico, Turkey, and the Philippines, have been involved with the issuance of catastrophe bonds. These are fixed-income securities that pay periodic coupons to the investor during the life of the bond and provide insurance to the country involved against a predefined set of natural disasters such as earthquakes. If a covered event occurs during the bond's life, the sponsoring country retains the bond principal to fund emergency relief and reconstruction work. The triggers are parametric as they depend on data providers such as the USGS. As shown in Chapter 3, cat bonds are an efficient tool for countries to transfer some of their natural disaster risk to the capital markets and a viable alternative to standard insurance coverage for less frequent, but more catastrophic events, which is a key-essential element of a Type II event. It is worth noting the crucial role the World Bank plays in the issuance of these contracts, assisting in the formulation of disaster risk management, offering off-the-shelf documentation, providing support with the preparation of the legal framework, and helping with operational framework service providers. Figure 4.6. presents a simplified scheme of how a cat bond works in practice.

FIGURE 4.6. Cat Bond Structure



Source: World Bank Treasury.

In February 2018, the World Bank issued a catastrophe bond that collectively provides insurance of 1.36 billion dollars in earthquake protection to the countries in the Pacific Alliance (PA): Chile, Colombia, Mexico, and Peru. This is the largest sovereign risk insurance transaction ever and the second largest issuance in the history of the catastrophe bond market.⁵⁹ The issuance consists of one

⁵⁹ The largest issuance as of today is a 1.5 billion dollars cat bond issued in May 2014 as “Everglades Re Ltd,” which is sponsored by Citizens (insurance company) and provides reinsurance protection against hurricanes to residential and commercial properties on the coast of Florida.

single bond with five tranches: one each for Chile, Colombia and Peru, and two for Mexico (each country decided on a particular region to insure). The PA originally sought 1 billion dollars in cat securities, but demand swelled to 2.5 billion dollars after 45 investors pledged interest to the deal.⁶⁰ Table 4.3 sums up the most relevant aspects of the PA Cat Bond issuance.

TABLE 4.3. Pacific Alliance Catastrophe Bond

Transaction Summary	
Nominal Amount:	USD 1.36 billion (with offers for USD 2.5 billion)
Classes:	Chile - USD 500 million Colombia - USD 400 million Mexico (a) - USD 160 million Mexico (b) - USD 100 million Peru - USD 200 million
Time to Maturity:	3 years for Chile, Colombia, and Peru 2 years for Mexico
Bond Coupon (per annum):	3-month USD LIBOR + Funding Margin (-0.2 per cent) + Risk Margin
Risk Margin:	2.5 per cent per annum for Chile and Mexico (a) 3 per cent per annum for Colombia 8.25 per cent per annum for Mexico (b)

Source: World Bank Treasury.

Cat bonds are a novel instrument in the world of risk management tools. Mexico was a pioneer in the usage of this kind of instruments, being the first sovereign to issue a cat bond back in 2006, the Cat-Mex. The government then renewed this contract through the World Bank's Multi-Cat platform, issuing new contracts in 2009, 2012, and 2017. Mexico benefited from this insurance in 2015 (hurricane Odile), 2016 (hurricane Patricia), and 2017 (the earthquakes of Southern Mexico and Mexico City). These earthquakes prompted Mexico to join the ongoing negotiations with Chile, Colombia and Peru, for the issuance of the PA Cat Bond. As noted in Chapter 3, a critical aspect affecting the price of issuance of this type of multi-country cat bond is the correlation between disasters across the countries involved. The lower the correlation, the lower the price. In the case of the PA Cat Bond, for a 3-year time horizon (which is the period used), the mean correlation between earthquakes for PA countries is 0.13. Note that this correlation would almost halve (to 0.07) if, for example, India were also included in the pool of countries because the tectonic faults affecting the PA countries are, of course, different from India's.

⁶⁰ See Latin Finance (2018).

Catastrophe Deferred Drawdown Option (Cat DDO)

As it does for DPOs, the World Bank also offers the option of DDOs for risk instruments in the region that provide coverage against natural disasters. In particular, the Cat DDO is a contingent credit line that provides immediate liquidity to countries in the aftermath of a natural disaster, when liquidity constraints are usually the highest. Under a Cat DDO, borrowers can secure immediate access to financing up to 500 million dollars or 0.25 percent of GDP (whichever is less). The Cat DDO has a “soft” trigger, as opposed to a “parametric” trigger (like cat bonds). In other words, the trigger is the declaration of a state of emergency due to a natural disaster (and not man-made disasters, such as wars or refugee crises), by the relevant authority. In order to gain access to the Cat DDO, the borrower must implement a disaster risk management program, which the Bank monitors on a periodic basis. Table 4.4 presents the Cat DDOs that have been approved since 2008, adding up to 3.2 billion dollars. In a more recent development, some Cat DDOs include provisions for states of emergency triggered by pandemic risks, such as the Zika virus.

TABLE 4.4. Approved Cat DDOs since 2008

Country	Fiscal Year	Amount (millions of USD)	% Disbursed
1. Costa Rica	2009	65	100
2. Colombia	2009	150	100
3. Guatemala	2009	85	100
4. Peru	2011	100	0
5. El Salvador	2011	50	100
6. Philippines	2012	500	100
7. Panama	2012	66	38
8. Colombia	2013	250	0
9. Sri Lanka	2014	102	100
10. Seychelles	2015	7	0
11. Peru	2015	400	0
12. Philippines	2016	500	0
13. Serbia	2017	70	0
14. Dominican Republic	2017	150	0
15. Kenya	2018	200	0
16. Romania	2018	493	0
TOTAL		3,188	

Source: World Bank Treasury.

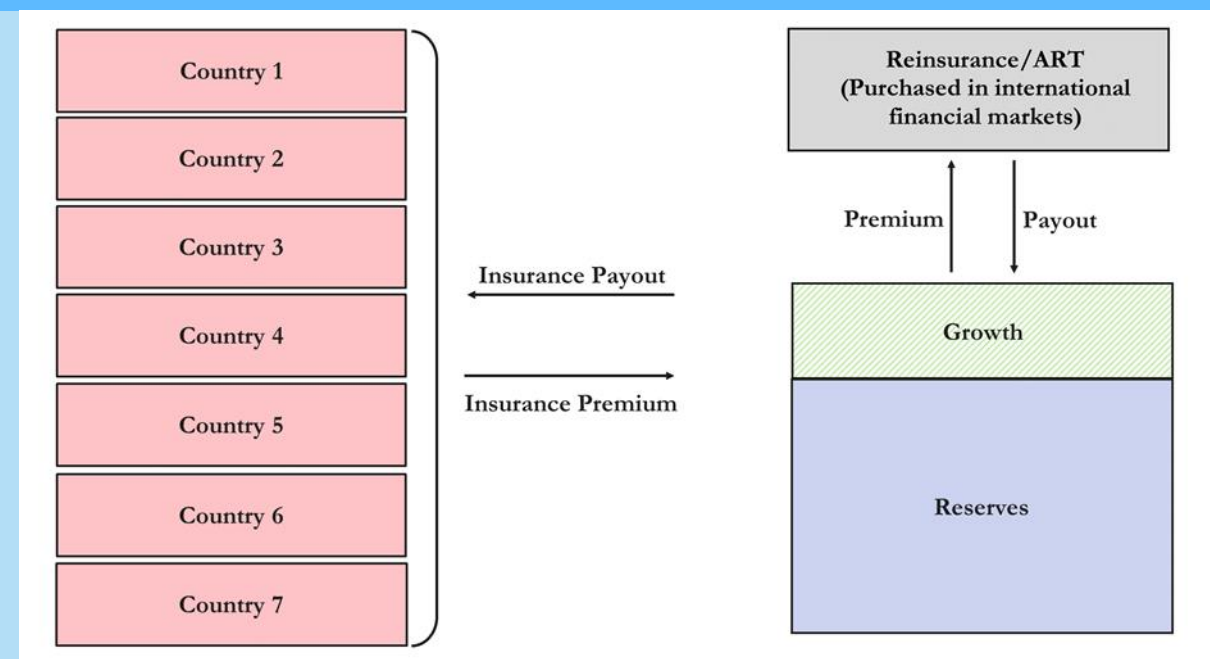
Fideicomiso Fondo de Desastres Naturales (Fonden)

Even though cat bonds are an attractive instrument to deal with natural disaster risk (as it has been shown in Chapter 3), countries may still decide, just as they do for other Type II events, to keep a catastrophe fund reserve. Among developing countries, the Mexican Fonden is one of the best examples of a fund created exclusively to deal with natural disasters ex-post. The Fonden was created in the late 1990's and has grown to such an extent that it was the platform through which the 2006 Cat-Mex was issued. To date, the fund holds around 500 million dollars and 0.4 percent of the yearly budget must be deposited in the Fonden. In turn, the fund includes smaller programs such as the *Fondo de Atención de Emergencias* and *Apoyos Parciales Inmediatos*, which provide resources and immediate assistance to affected communities in terms of temporary shelter, medications, and reestablishing public services, among others.

Caribbean Catastrophe Risk Insurance Facility (CCRIF-CA)

As discussed above, the existence of a catastrophe fund reserve like Fonden in Mexico makes sense since the size of the country is so large that there is a lot of room for risk sharing within Mexico. In other words, not all natural disasters occur simultaneously everywhere in Mexico. In contrast, when turning to hurricanes in the Caribbean (the most important type of natural disaster in this sub-region), it proves impractical for each individual country to have a Fonden-like type of catastrophe fund reserve because the size of countries (being much smaller than Mexico) simply does not support an economically efficient way of risk sharing within each country.

FIGURE 4.7. Risk Pools: CCRIF-CA



Source: World Bank Treasury.

In this case, and because typically not all Caribbean countries are simultaneously hit by a hurricane, it proves more efficient to share risk *across* Caribbean countries rather than within each individual country. Out of all Caribbean countries, between 1 and 3 are typically affected by a storm every year.⁶¹ The multi-country risk pool sharing CCRIF was initially capitalized by the participating countries themselves with support from donors. Each year, as the pool is depleted, participating countries replenish it in proportion to their probable use of funds from the pool. The pool retains some of the risks transferred by the participating countries and, in turn, transfers some of the risk to reinsurance markets where this is cost-effective. Countries pay approximately half the price that they would if they approached the reinsurance industry on their own. Just as the cat bond, payments have a parametric trigger. Countries can obtain as much as 20 percent of expected losses through CCRIF. Figure 4.8 shows a simplified scheme of how the CCRIF works. A recent innovation in the CCRIF has been the addition of Central American countries to the pool (CCRIF-CA).

Preventive Measures

One of the best preventive measures to reduce the exposure to earthquakes is to build seismic-resistant buildings (e.g., almost 90 percent of the buildings in Tokyo are able to withstand earthquakes). In the case of LAC, Chile is among the countries with the highest incidence of earthquakes. To improve their resilience to this type of events, the country developed a sophisticated anti-seismic urban code regulation. For example, in 1922 (before Chile developed this anti-seismic construction code), an earthquake of 8.3 Richter in Vallenar (near Coquimbo) caused the death of 100 people; that is, 62 for every 100,000 people. After a significant improvement in anti-seismic building structures, when the country suffered in 2015 an earthquake of 8.3 Richter near Coquimbo, it caused the death of 19 people, which amounts to 3 for every 100,000 people, about 5 percent of the implied death toll in 1922.⁶²

Ex-post Aid

Ex-post aid is of particular importance in LAC for the case of hurricanes. Central America and the Caribbean are among the most affected. Because of hurricanes, 26 million people have fallen into poverty according to World Bank estimates.⁶³ The World Bank has played a central role in providing ex-post aid to help the most vulnerable. For instance, after Irma (one of the most devastating hurricanes that hit the Caribbean in 2017) the World Bank helped the island of Sint-Maarten with a loan of 580 million dollars (about 30 percent of its GDP) for reconstruction and to increase resilience following the devastation caused by hurricane Irma.⁶⁴

⁶¹ See World Bank (2017a).

⁶² Approximate calculations based on historical Census data available at *Instituto Nacional de Estadísticas de Chile* and EM-DAT.

⁶³ See World Bank (2017b).

⁶⁴ See World Bank (2018).

Black Swans

As discussed in Chapter 2, Black Swan events have an unpredictable nature and are typically devastating. Given their unpredictability, it proves virtually impossible (by definition) to develop specific policies to prevent black swans *per se*. Having said that, ex-post aid to relief the damage and minimize, insofar as possible, human and/or economic losses is clearly of great importance. In this context, it is important to develop strong economic foundations, including a sound monetary and fiscal framework, preparedness for relief assistance, contingent plans for various emergencies, and strong institutions, in order to minimize the ex-post effects of black swans.

Two excellent examples of highly effective ex-post aid are the Great Depression in the United States and the Global Financial Crisis of 2008 (see Table 2.3). The Great Depression began in the United States after the stock market crash of October 1929 and lasted for about a decade. It was the most severe fall in economic activity, consumption, investment, and employment in the modern history of advanced economies, with the unemployment rate reaching 25 percent in 1933 in the United States, and ranging in Europe from 20 percent in the United Kingdom to 36 percent in Germany. When President Roosevelt took office in 1933 in the United States, he enacted the New Deal which consisted of a series of programs, public work projects, financial reforms, and regulations aimed at helping the poor and unemployed, stimulating the economy, and reforming the financial system. To have a sense of the importance of the New Deal, on a per capita basis in 2009-adjusted dollars, the total federal spending of the New Deal was almost twice as large as that of the Recovery Act (5,231 dollars in the New Deal compared to 2,738 dollars in the Recovery Act).⁶⁵

The second example is the Global Financial Crisis of 2008. While like in most financial crises, some building-up components may have been expected to some degree, the timing, and more importantly, the scale and international nature of the crisis was arguably unpredictable. The most “predictable” component was the subprime mortgage crisis in the United States, which resulted from an expansion of mortgage credit to highly risky borrowers and led to a housing price bubble. The collapse of this bubble developed into a full-blown international banking and stock market crises which, in turn, also jeopardized the sovereign debt of many European countries (most notably Greece). In the United States, the Global Crisis was dealt with a large fiscal stimulus package (including the Economic Stimulus Act of 2008 and the American Recovery and Reinvestment Act of 2009), monetary stimulus (the Federal Reserve reduced the federal funds rate from 5.25 percent in September 2007 to a range of 0-0.25 percent in December 2008) and large scale asset purchase (LSAP) programs (which provided support for the housing market, which was the epicenter of the crisis and recession, and helped push down longer-term public and private borrowing rates).

⁶⁵ See Dupor (2017).

Opportunities and Challenges Ahead

There is no escape from the fact that we live in a risky world. LAC is certainly not immune to this phenomenon and is, in fact, one of the riskiest regions in the world. As argued in Chapter 2, this makes it particularly important to understand the different types of risk and what insurance mechanisms may be available. In fact, we have learned that a country's ability to insure against risk varies a great deal, from easily insurable risk (Type I risks that are characterized by a normal distribution) to non-insurable risk (black swans). As a general proposition, the fatter the tails of the distribution describing a certain risk, the less market insurance will be available, and the more ex-post aid will be needed.

Having said that, our understanding of risk and insurance evolves continuously. Just as one example, a multi-country catastrophe bond (like the Pacific Alliance cat bond to insure against earthquakes) would have been unthinkable some time ago. Finance theorists keep working out theoretical formulas for insuring risk, empiricists have access to extraordinary large databases that allow them to uncover risk regularities like never before, practitioners combine all this new knowledge with their familiarity of the actual world and convince policymakers to try new things, and financial markets are ever more willing to enter into insurance contracts where everybody wins. In fact, there is little doubt that, in the near future, we will see cat bonds that cover different regions in the world (to achieve greater risk diversification) and our knowledge of the costs and physical dynamics of hurricanes will allow us to enter into more efficient ex-ante insurance contracts.

In sum, while the world will continue to be a risky place, our increasing ability to manage risk will, effectively, make it a safer world.

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Appendices

Appendix A: Annual Growth for LAC Countries

TABLE A.1. Annual Real GDP Growth Rates for LAC Countries

Real GDP Growth (as percentage)		2016	2017	2018f	2019f
Region	Country				
SA	Argentina	-1.8	2.9	-2.5	-1.6
	Brazil	-3.5	1.0	1.2	2.2
	Bolivia	4.3	4.2	4.5	4.3
	Chile	1.3	1.5	4.0	3.5
	Colombia	2.0	1.8	2.7	3.3
	Ecuador	-1.2	2.4	1.5	1.6
	Guyana	3.4	2.1	3.4	4.8
	Paraguay	4.3	4.8	4.0	3.9
	Peru	4.0	2.5	3.9	3.8
	Suriname	-5.1	-2.1	1.4	1.6
	Uruguay	1.7	2.7	2.1	2.3
	Venezuela, RB	-16.5	-14.5	-18.2	-8.4
MEX	Mexico	2.9	2.0	2.3	2.3
CA	Belize	-0.5	1.2	1.5	1.9
	Costa Rica	4.2	3.2	2.7	2.6
	El Salvador	2.6	2.3	2.8	2.5
	Guatemala	3.1	2.8	2.6	2.7
	Honduras	3.8	4.8	3.6	3.8
	Nicaragua	4.7	4.9	-3.8	-0.5
	Panama	5.0	5.4	4.5	5.4
CB	Antigua and Barbuda	5.3	2.8	3.5	3.0
	The Bahamas	0.2	1.3	2.5	2.2
	Barbados	1.6	0.9	0.5	0.8
	Dominica	2.6	-4.2	-16.3	12.2
	Dominican Republic	6.6	4.6	5.8	5.1
	Grenada	3.7	5.1	3.4	3.3
	Haiti	1.5	1.2	1.6	2.3
	Jamaica	1.4	0.7	1.7	1.8
	St. Kitts and Nevis	3.1	2.6	3.5	3.2
	St. Lucia	3.4	3.8	2.1	2.5
	St. Vincent and the Grenadines	1.3	0.5	1.2	1.6
Trinidad and Tobago	-6.0	-2.3	0.7	0.9	
LAC (weighted average)		-1.0	1.1	0.6	1.6
SA (weighted average)		-2.6	0.5	-0.1	1.2
MCC (weighted average)		3.1	2.4	2.5	2.6
CA (weighted average)		3.8	3.7	2.8	3.2
CB (weighted average)		2.9	2.4	3.7	3.5

Notes: "f" stands for forecast. Figures for Antigua and Barbuda, Barbados, Dominica, St. Kitts and Nevis and The Bahamas from WEO. Sub-regional figures are weighted averages. Weights are calculated using WEO's 2016 GDP. Sources: World Bank staff estimates (September 2018) when available, otherwise WEO (April 2018).

Appendix B: Definition of Regions Used in Chapter 2

This appendix covers the countries included in each region of Tables 2.1, 2.2, 2.4, 2.5, 2.6, and 2.7.

Table 2.1 and 2.2 include the full sample of countries for each region, which is described below. Note, however, that the countries included for each variable of interest may vary due to data availability.

Advanced Economies include Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Malta, Netherlands, New Zealand, Norway, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, United Kingdom, and United States.

Emerging Asia includes American Samoa, Bangladesh, Bhutan, Brunei Darussalam, Cambodia, China, Cook Islands, Fiji, French Polynesia, Guam, Hong Kong, India, Indonesia, Kiribati, Korea, Dem. People's Rep., Korea, Rep., Lao PDR, Macao, Malaysia, Maldives, Marshall Islands, Micronesia (Fed. Sts.), Mongolia, Myanmar, Nauru, Nepal, New Caledonia, Northern Mariana Islands, Palau, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Sri Lanka, Taiwan, Thailand, Timor-Leste, Tokelau, Tonga, Tuvalu, Vanuatu, Vietnam, and Wallis and Futuna.

Emerging Europe includes Albania, Andorra, Azores Islands, Belarus, Bosnia and Herzegovina, Bulgaria, Channel Islands, Croatia, Cyprus, Faroe Islands, Gibraltar, Hungary, Isle of Man, Kosovo, Latvia, Liechtenstein, Lithuania, Macedonia (FYR), Moldova, Monaco, Montenegro, Poland, Romania, Russia Federation, San Marino, Serbia, Turkey, and Ukraine.

Latin America and the Caribbean include Anguilla, Antigua and Barbuda, Aruba, The Bahamas, Barbados, Bermuda, British Virgin Islands, Cayman Islands, Cuba, Dominica, Dominican Republic, Grenada, Guadeloupe, Haiti, Jamaica, Montserrat, Netherlands Antilles, Puerto Rico, Sint Maarten (Dutch part), St. Kitts and Nevis, St. Lucia, St. Martin (French part), St. Vincent and the Grenadines, Trinidad and Tobago, Turks and Caicos Islands, and Virgin Islands (U.S.) in the Caribbean sub-region; Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama in the Central America sub-region; and Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, French Guiana, Guyana, Mexico, Paraguay, Peru, Suriname, Uruguay, and Venezuela in South America and Mexico sub-region.

Middle East and North Africa include Afghanistan, Algeria, Armenia, Azerbaijan, Bahrain, Canary Islands, Djibouti, Egypt, Georgia, Iran, Iraq, Jordan, Kazakhstan, Kuwait, Kyrgyz Republic, Lebanon, Libya, Mauritania, Morocco, Oman, Pakistan, Qatar, Saudi Arabia, Somalia, Sudan, Syrian Arab Republic, Tajikistan, Tunisia, Turkmenistan, United Arab Emirates, Uzbekistan, West Bank and Gaza, Yemen, Rep.

Sub-Saharan Africa includes Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo, Dem. Rep., Congo, Rep., Cote d'Ivoire, Equatorial Guinea, Eritrea, Ethiopia, Gabon, The Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritius, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, South Africa, South Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, and Zimbabwe.

Note that regarding spreads and yields, we are only considering Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Slovak Republic, Slovenia and Spain in Advanced Economies. The reason is that we are calculating the spread between Germany and the main European countries of a 10 year euro-denominated bond. For the other regions we are using the J.P. Morgan Emerging Market Bond Index, including India, Indonesia, Malaysia, Mongolia, Philippines, Sri Lanka, Vietnam, Belarus, Croatia, Hungary, Latvia, Lithuania, Poland, Romania, Serbia, Turkey, Ukraine, Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela, RB, Armenia, Azerbaijan, Egypt, Georgia, Iraq, Kazakhstan, Kuwait, Lebanon, Morocco, Pakistan, Tunisia, Cote d'Ivoire, Ethiopia, Gabon, Ghana, Kenya, Mozambique, Namibia, Niger, Nigeria, Senegal, South Africa, Tanzania, and Zambia.

Table 2.4 and 2.5 are a subsample of the countries specified above.

Regarding the last two tables in Chapter 2, Table 2.6 includes the full sample of countries (see below) where a natural disaster took place and Table 2.7 is a subsample that focuses on earthquakes, floods and storms.

East Asia and Pacific include American Samoa, Australia, Brunei Darussalam, Cambodia, China, Cook Islands, Fiji, French Polynesia, Guam, Hong Kong, Indonesia, Japan, Kiribati, Korea, Dem. People's Rep., Korea, Rep., Lao PDR, Macao, Malaysia, Marshall Islands, Micronesia (Fed. Sts.), Mongolia, Myanmar, New Caledonia, New Zealand, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Taiwan, Thailand, Timor-Leste, Tokelau, Tonga, Tuvalu, Vanuatu, Vietnam, and Wallis and Futuna.

Europe and Central Asia include Albania, Armenia, Austria, Azerbaijan, Azores Islands, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Kazakhstan Kyrgyz Republic, Latvia, Lithuania, Luxembourg, Macedonia (FYR), Moldova, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, Serbia, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Tajikistan, Turkey, Turkmenistan, Ukraine, United Kingdom, and Uzbekistan.

Latin America and the Caribbean includes the countries listed for the same region for Tables 2.1. and 2.2. plus Martinique and Saint-Barthélemy.

Middle East and North Africa includes Algeria, Bahrain, Canary Islands, Djibouti, Egypt, Arab Rep., Iran, Islamic Rep., Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Palestine (State of), Saudi Arabia, Syrian Arab Republic, Tunisia, United Arab Emirates, and Yemen, Rep.

North America includes Canada and United States.

South Asia includes Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka.

Sub-Saharan Africa includes the countries listed for the same region for Tables 2.1. and 2.2. plus Mauritania and Somalia.

Appendix C: Two-Country, Closed-Economy Model

Based on the seminal work of Lucas (1978), this appendix develops the simplest possible general equilibrium model where a call option can be priced.⁶⁶

Consider a closed economy inhabited by a representative consumer who lives for only two periods. His/her income in period 1 is deterministic and equal to y . In period 2, however, his/her income is stochastic and given by

$$y_2 = y(1 + x),$$

where x is a continuous random variable.

The consumer's lifetime utility function is given by

$$u(c_1, c_2) = \frac{c_1^{1-\gamma} - 1}{1-\gamma} + \beta \mathbf{E} \left(\frac{c_2^{1-\gamma} - 1}{1-\gamma} \right), \quad (C.1)$$

where c_1 and c_2 denote consumption in periods 1 and 2, respectively, β is the discount factor, γ is the coefficient of risk aversion, and \mathbf{E} denotes expected values.

For every possible choice of c_2 and realization of x , the following intertemporal budget constraint must hold:

$$c_1 + \frac{c_2}{1+r} = y + \frac{y(1+x)}{1+r},$$

where r is the real interest rate of the risk-free bond. Proceeding with the usual maximization, we can derive the standard stochastic Euler equation:

$$c_1^{-\gamma} = \beta(1+r)\mathbf{E}(c_2^{-\gamma}).$$

In equilibrium, $c_1 = y$ and $c_2 = y(1+x)$. Hence, r can be expressed as

$$\frac{1}{1+r} = \beta \mathbf{E}[(1+x)^{-\gamma}]. \quad (C.2)$$

Notice that if x were non-stochastic (and equal to zero, so that the endowment is the same across periods) or $\gamma = 0$ (i.e., if the consumer were risk-neutral), then $1+r = 1/\beta$, as expected.

By the same token, for an underlying asset with price s_1 in period 1 and a stochastic price s_2 in period 2, we obtain:

$$s_1 = \beta \mathbf{E}[(1+x)^{-\gamma} s_2]. \quad (C.3)$$

The (real) price of a call option (denoted by p_k) for this underlying asset with a strike price k in period 2 is given by

⁶⁶ The reader is referred to Lama *et al.* (2018) for details.

$$p_k = \beta \mathbf{E}[(1+x)^{-\gamma} \max(s_2 - k, 0)]. \quad (\text{C.4})$$

To price the call option, we need to specify the distribution for x and s_2 . Following conventional finance models, we will assume that $1+x$ follows a log-normal distribution such that

$$\log(1+x) \sim \mathcal{N}\left(-\frac{\sigma_x^2}{2}, \sigma_x^2\right).$$

In this case, it follows that equation (C.2) becomes

$$\frac{1}{1+r} = \beta e^{\gamma(\gamma+1)\frac{\sigma_x^2}{2}}.$$

In turn, equation (C.3) can be written as:

$$s_1 = \frac{e^{-\gamma(\gamma+1)\frac{\sigma_x^2}{2}}}{1+r} \mathbf{E}[(1+x)^{-\gamma} s_2].$$

We now assume that:

1. $\log(s_2)$ follows a normal distribution, so that $\log(s_2) \sim \mathcal{N}(\log(s_1) + \mu_s, \sigma_s^2)$.
2. The correlation between $\log(1+x)$ and $\log(s_2)$ is given by $\rho_{x,s}$.
3. The non-arbitrage condition across asset returns implies that

$$\mu_s = \log(1+r) + \gamma\sigma_x^2 - \frac{\sigma_s^2}{2} + \gamma\rho_{x,s}\sigma_s\sigma_x.$$

Given these assumptions – and after some lengthy algebra detailed in Lama *et al.* (2018) – it can be shown that equation (C.4) becomes

$$p_k = e^{\gamma\sigma_x^2} s_1 \mathbf{N}(\widetilde{k}_1) - \frac{k}{1+r} \mathbf{N}(\widetilde{k}_1 - \sigma_s),$$

where

$$\widetilde{k}_1 = \frac{\log(s_1/k) + \log(1+r) + \sigma_s^2/2 + \gamma\sigma_x^2}{\sigma_s},$$

where $\mathbf{N}(\cdot)$ is the cumulative distribution function for a standard normal variable.

Under the assumption of risk neutrality (i.e., $\gamma = 0$), we get the standard Black-Scholes formula for the price of a call option:

$$p_k = s_1 \mathbf{N}(d_1) - \frac{k}{1+r} \mathbf{N}(d_1 - \sigma_s),$$

which is the same Black-Scholes formula as in Chapter 3 (taking into account that this is a two-period model).

Appendix D: Pricing for Rare Events in a Two-Country Model

Consider a two-country model where countries are identical. As in the previous model, income is deterministic in period 1 (and equal to y in both countries) and stochastic in period 2 and given by

$$y_2^i = y(1 - v^i b),$$

where a superscript $i = 1, 2$ denotes the two countries, $v^i = 1$ in the case of a disaster event in country i and $v^i = 0$ otherwise, and b denotes the size of the disaster event. For instance, $v^1 = 1$ and $v^2 = 0$ would indicate that country 1 suffers a disaster event (e.g., an earthquake or a hurricane) of size b whereas country 2 does not.

The joint probability distribution for v^1 and v^2 is given by:

$$\begin{aligned} v^1 = 1, v^2 = 1 & \text{ with probability } p^2 q, \\ v^1 = 1, v^2 = 0 & \text{ with probability } p - p^2 q, \\ v^1 = 0, v^2 = 1 & \text{ with probability } p - p^2 q, \\ v^1 = 0, v^2 = 0 & \text{ with probability } 1 - 2p + p^2 q. \end{aligned}$$

where, to ensure well-defined probabilities, we assume that $q > 0$ and $q \leq 1/p$. Naturally, these four probabilities add up to 1. Notice that, under this specification, p is the unconditional probability of having a disaster event in each country and the parameter q controls how correlated are the disaster events across countries.

The correlation between v^1 and v^2 is given by

$$\text{corr}(v^1, v^2) = \frac{p(q - 1)}{1 - p}.$$

Hence, if $q = 1$, the correlation is zero and, if $q = 1/p$, the correlation will be 1.

Suppose that there are contingent bonds available at a cost n^i in period 1. This contingent bond pays 1 unit of consumption if a disaster event occurs in period 2 in country i (i.e., $v^i = 1$) and zero otherwise (i.e., $v^i = 0$). Country 1 can buy B^1 units of the contingent bond that pay if $v^1 = 1$ and sell B^2 units of the bond that pay if $v^2 = 1$.

Preferences in each country continue to be given by equation (C.1). As shown in Lama *et al.* (2018), standard maximization problems in each country and the symmetry across countries (which means that $n^1 = n^2 = n$) imply that each country buys an amount of each bond equal to $b/2$, which ensures full risk sharing in the sense that if a disaster event occurs in either country, the endowment available in both countries will be equal to $y_2^i = y(1 - b/2)$. Furthermore, the price of the bond is given by

$$n = \beta[p^2 q(1 - b)^{-\gamma} + (p - p^2 q)(1 - b/2)^{-\gamma}].$$

Notice that when the correlation is one (i.e., $q = 1/p$), the price is given by

$$n = \beta[p(1 - b)^{-\gamma}].$$

When the correlation is one, whenever it happens, the disaster event hits both countries and, thus, available endowment is $y(1 - b)$.

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