Chapter 18
Regime-Switching in the Volatility of Mexican Pension Fund Returns

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Abstract Several Latin American countries reformed their retirement-pension systems during the 1980s and 1990s because the previous funded or pay-as-you-go systems were deemed insufficient to support the rapidly growing aging populations. Mexico was no exception, and in 1997 it replaced its traditional pay-as-you-go system with a privately managed scheme, in which contributions by or on behalf of active workers are deposited in individual accounts and channeled to a privately managed pension fund. The main function of these private pension fund managers is to invest active workers' contributions in financial securities portfolios to maximize returns and minimize risks, increasing the accumulation in individuals' accounts. The defined-contribution system, as it is known, manages workers' accumulated resources to support them upon retirement. According to government authorities, the system also has the advantage of increasing domestic savings due to the compulsory nature of workers' savings, and investing them to foster economic growth. Since the defined-contribution system was implemented in Mexico, its investment regime has undergone several changes. At the end of 2004, a new type of basic pension fund, SIEFOREs (Sociedades de Inversion Especializadas de Fondos para el Retiro), was created, and a new 2007 amendment allowed for the creation of three new different types of pension funds designed to serve workers pertaining to different age ranges, encompassing their complete life span. This chapter analyzes the conditional volatility of SIEFOREs' returns based on a model according to which GARCH

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parameters follow a two-regime Markov-chain process. Since all the available information for each SIEFORE is used, a thorough analysis is carried out, taking into account different critical facts that have influenced retirement pension fund risk. The study's results and conclusions are useful for retirement pension fund managers, as well as for the system's regulators and supervisors.

Keywords Pension funds · Markov-switching GARCH models · Return volatility · Risk returns

18.1 Introduction

Latin American countries[1] executed deep structural reforms to privatize their retirement pension systems during the 1980s and 1990s as a response to hard evidence that traditional *fully funded* or *pay-as-you-go* systems were insufficient to support an increasingly aging population and a declining contribution base. Before transforming the traditional public system to a private scheme, most shifted from a *funded* to a *pay-as-you-go* scheme since the former was expected to generate an operational deficit after some years. Notwithstanding, the latter did not resolve the retirement pension systems' liquidity problems because most workers' accumulation was not enough to fund their retirement due to long periods of unemployment and the coexistence of parallel and nontransferable pension regimes that workers joined and exited as they changed jobs.

Mexico's pension system was subject to similar problems, and in 1997, the country's government decided to replace the then existing *pay-as-you-go* system with a privately managed retirement pension scheme that followed the blueprint of the Chilean retirement pension system, which was introduced during the early 1980s and had proved successful after 15 years of operation. Under the new scheme, contributions by, or on behalf, of active workers are deposited in individual accounts, and all the resources in the individual accounts are channeled to privately managed specialized pension funds. Their objective is to invest the workers' contributions in financial securities portfolios to maximize returns and minimize risk. Fund administrators manage the savings so that the accumulation of periodic contributions plus retained earnings build up, and the balance at the end of a worker's working life is enough to support her in retirement. Different private funds compete in the market for the workers' savings with active publicity and promotion campaigns. However, the funds' performance, which should be one of the most powerful sale arguments, is made public by CONSAR[2] the industry's

[1]Peru in 1993, Argentina and Colombia in 1994, Uruguay in 1996, Bolivia in 1997 and El Salvador in 1998 (Martínez-Preece and Venegas-Martínez 2015)

[2]The acronym of Mexican regulatory entity for the Mexican pension system, especially for the supervision and regulation of SIEFORES: Comisión Nacional del Sistema del Ahorro para el Retiro or "National Retirement Savings Commission".

government supervisor, only once a month. That report contains very crude measures of return and volatility, and savers have to make their choice of SIEFORE based on it. The report's limited information is unquestionably insufficient to reveal the dynamic characteristics of the system and to support the analysis of SIEFOREs with decision-making objectives. The living conditions that Mexican workers will face upon retirement depends on the characteristics of the prevailing retirement pension system. Therefore, the analysis of retirement pension funds' performance in Mexico deserves greater attention, but very little research has been produced on it. The fundamental motivation of this work is to perform an in-depth study of SIEFOREs' evolution in recent times, including their performance during periods of high and low volatility.

This chapter analyzes the conditional volatility of SIEFOREs' returns using a model in which GARCH parameters switch between two regimes following a Markov-chain process. Each SIEFORE's available data is used in the analysis to consider critical facts that have influenced the pension funds' risk. The estimation results support several conclusions that are relevant for retirement pension fund managers, as well as for regulators and supervisors, and contribute to a better understanding of the characteristics of the industry, which, we hope, can enhance the long-term benefits enjoyed by future pensioners.

18.2 Literature Review

The significant progress observed in health sciences, as well as improvements in the living standards of vast population contingents in every region of the world, and the extraordinary solutions to a number of social, educational, and participation problems that are nowadays supported by modern technological breakthroughs, have together created a favorable environment for individuals across the world to live longer lives. At the same time, the world's population has experienced a slowdown in fertility rates, in some cases explained by intended demographic policies (as in China and other emerging countries), rapidly changing social values, the new role played by women in the labor force, and changing societal values.

However, living longer lives comes with the challenge of counting on adequate long-term funding to make them reasonably good and comfortable. Besides, diminishing birth rates imply fewer future contributors to traditional *pay-as-you-go* or *defined-benefit* retirement pension systems, posing a challenge to public policy designers responsible for retirement pension systems. As lucidly expressed by Barr and Diamond (2009), the traditional pension systems, with fixed contribution rates awarding monthly benefits at a given retirement age, are no longer congruent with the longer retirement period that comes with extended life expectancy and increased dependency rates associated to declining fertility.

The new demographic trends exert significant strain and raise relevant concerns for traditional defined-benefit pension schemes, posing the question of their long-term sustainability (see, for example, Verbič and Spruk 2014; Peinado and Serrano

2014). For these reasons, new ways and schemes to provide adequate retirement plans are currently under serious consideration all over the world.

Among other alternative schemes, a system that has attracted the attention of governments in several countries and deserved the scrutiny of serious academic studies due to its solid foundations and capacity to adapt to different demographic contexts is the *defined-contribution* pension system (Williamson et al. 2012). This system originated during the early 1980s, when the Chilean government opted for the first system of its kind, in the context of major structural reforms seeking to improve the performance of that country's economy, including a generalized privatization of state-owned firms (James 2005; Santillán-Salgado et al. 2010). The name given to the entities that comprised the new system was "Administradoras de Fondos de Pensiones" (AFP)—*pension fund managers*—and they brought significant macroeconomic and financial benefits to the country. Results were so satisfactory as to justify that during the following 20 years, the scheme was adopted in countries from Latin America, Eastern and Central Europe, and Asia (James 2005). However, the adoption of defined-contribution systems has not been limited to emerging countries as they have also been very successfully introduced in a number of developed countries, including Canada, Ireland, the United Kingdom, and the United States.

In recent decades, the literature expanded rapidly to study a wide variety of regulatory issues, operational challenges, microeconomic aspects, macroeconomic consequences, and, in recent years, the performance of pension fund investment portfolios. Some of the most influential works in the field of the defined-contribution retirement pension system include those of Orzag and Stiglitz (2001), Calderón-Colín et al. (2010), Fuentes et al. (2010), Alonso et al. (2015), De la Torre et al. (2015), Martínez-Preece and Venegas-Martínez (2014), and Santillán-Salgado et al. (2016).

Consistent with the aims of this study, the succinct literature review presented here centers on representative studies that address the financial performance of *defined-contribution* retirement pension funds. Paraphrasing Martínez-Preece and Venegas-Martínez (2014), neither savings nor economic growth is the ultimate objective of the design of pension programs (Diamond and Stiglitz 1974). However, it should be considered that the possibility of increasing total savings, even when it implies exposing workers to greater risks in order to make their savings support economic growth, is acceptable only if it has been carefully analyzed and if, ultimately, it results in greater well-being for the population.

Among the first studies interested in addressing the question of how successful defined-contribution plans would be in providing pensions to workers once they retire, Blake et al. (2001) make a significant contribution by describing the way pension provision systems undergo the transition from an unfunded social security scheme to a private funding framework and, within that category, from a defined-benefit system toward a defined-contribution system. In their work, they describe the huge transfer of risk from the previous bearers, namely taxpayers and corporate sponsors, toward the individual agents who participate in a defined-contribution system. To further the understanding of the implications of that transition, they estimate the value at risk (VaR) during the accumulation phase of defined-contribution pension plans implementing diverse asset-return models, such as models with stationary moments, or regime-switching models and at the same time explore different asset-allocation strategies, again using a variety of alternatives (static and dynamic). The authors reach four important conclusions, the first of which is particularly worrying because, according to the authors, defined-contribution plans can be "extremely risky" compared to a defined-benefit benchmark system. Their second conclusion is that VaR estimates are highly sensitive to what kind of asset-allocation strategy is followed by the fund managers. Interestingly, the third conclusion is that a static asset-allocation strategy that gives a high weight to equity assets achieves substantially better results than other dynamic strategies investigated. Lastly, their fourth conclusion, consistent with the previous one, is that less risky bond-based asset-allocation strategies require savers to make significantly higher contributions to achieve similar retirement pensions as riskier equity-based strategies.

The defined-contribution system that has prevailed in Mexico since 1997 is described in some detail by Martínez-Preece and Venegas-Martínez (2014). According to these authors, one of the main features of the system is that it is managed by the private sector through individual accounts that concentrate the contributions made by workers, employers, and the government. The minimum period that a worker needs to contribute to the system is 25 years, and the pension received will depend on the individual record of each worker. This means that the balance of the individual worker's SIEFORE upon retirement will depend on the time during which she has made contributions, of the amounts deposited and of the yields accumulated throughout her working life. This last feature is linked to financial market performance since the worker's savings are used to purchase financial securities. So the total accumulation in the worker's retirement account will depend on the assets' price changes and accumulated yield that have built up in the individual's investment portfolios. That fact justifies a detailed study of the market performance of SIEFOREs and exploring their risk-return characteristics. In order to study the market risk performance of two types of SIEFOREs, the SIEFORE Básica I (SB1) and the Siefore Básica 2 (SB2), during the period from July 1, 1997, to December 31, 2010, for SB1 and from September 1, 2004, to December 31, 2010, for SB2, Martinez-Preece and Venegas-Martínez use an equally weighted performance benchmark of each SIEFORE type and an ARIMA-GARCH model to examine their dynamic returns and volatility. The authors also analyze the risk premium of both types of funds. One of the most relevant findings reported by these authors is that the yields obtained by these two types of funds during the period of analysis are not sufficient to compensate for the additional risk assumed by pension funds, whose portfolios include a variable income component. More specifically, they show that, in terms of mean-variance efficiency measured with Sharpe ratios, the SB1s underperformed the most conservative SB2s due to the higher volatility of the former (as expected) and to the asymmetry of the GARCH process inherent to the time series. The authors conclude with a reflection that seems to be right given the compulsory nature of savings SIEFOREs for workers, analyzing their financial risk and, in particular, the market risk, is of utmost importance since precisely the latter is the one that affects the total value of the accumulated retirement funds upon which the workers will depend at the end of their working life. They also emphasize that there is an unsatisfied need for better SIEFORE financial performance measures.

A study by Tecnológico de Monterrey on the defined-contribution Mexican retirement pension system discusses at length its antecedents; its macroeconomic impact on the labor market, on the public finances of the country, and on savings; and several other economic aspects (Fuentes-Castro 2014). Among the many interesting results of the analysis of the system and of its impact on the Mexican financial system, the reported findings suggest that the recent pension reform has contributed to the development of the country's financial sector, augmented the depth of the long-term debt markets in Mexico, and contributed to reduce the cost of long-term funding. Also, based on the results a vector error correction model, the report indicates that the evolution of the SIEFORE Granger affects the Mexican stock index but not the other way around. In brief, one of the relevant conclusions of the study is that pension funds can influence the financial system. However, the conclusions of that study are particularly relevant for the present work. Firstly, the degree of diversification of the assets held by the SIEFOREs represents an area of opportunity for improvement. Furthermore, that analysis explores whether some SIEFOREs replicate the strategy of other SIEFOREs and concludes that the correlation between different SIEFORE returns show high degrees of association and that by using a Granger-causality analysis, it can be concluded that some of the SIEFOREs lead the rest. The study explores how active the SIEFOREs are in trading and if they buy and sell securities from each other. It also finds that assets' holdings augmented when their returns increased; i.e., there is a positive correlation between an asset purchase and its performance. The evidence is clear in the case of international stocks, domestic private debt, structured products, international bonds, and government bonds. The study concludes with a list of recommendations aimed to improve the accumulation of savings, the stability of the system, and a more conscious participation of the population.

Martínez-Preece and Venegas-Martínez (2014) again undertake the analysis of the financial performance of Mexican pension funds with the intention of analyzing its market behavior and, more specifically, the volatility of the yields of different types of pension funds during the period from April 1, 2008, through December 31, 2014 (i.e., daily information of the four types of pension funds for almost 7 years). The authors attempt to determine if the pension system in Mexico is sustainable, considering its endowment and operating conditions. In the empirical part of their study, the authors model the dynamics of SIEFOREs' yield volatility using the SIEFOREs' indices, which are quoted in the Mexican Stock Exchange and published by CONSAR for the stated period of analysis. To model the SIEFOREs' risk premium volatility, the authors chose a GARCH-M model. The output of the GARCH-M model shows that the SIEFORE yields' negative perturbations are larger than the positive perturbations; i.e., there is asymmetry in volatility. For that reason, the authors opt for an EGARCH model, whose adjustment is quite satisfactory, which confirms that there are no remaining GARCH effects that require further adjustments. The estimation results of the EGARCH model confirm the presence of significant asymmetry coefficients in all four SIEFOREs' risk premia. The conditional volatility obtained for the SB4 with the GARCH-M model is very high, almost 50% during the 2008 financial crisis. In contrast, the conditional volatility observed for the more conservative SB1 yields is the lowest with respect to its peers. Based on their statistical analysis, Martínez-Preece and Venegas-Martínez conclude that under a pensionary system with low contributions and an unstable labor market that results in a discontinuity of the workers' pension lifetime savings accumulation, the financial stability of the system becomes a key element to guarantee satisfactory pensions in the future. So they ask the question: how many of the workers in the system will accumulate enough savings so as to enjoy a retirement pension above the minimum guaranteed pension? To answer this question, they make a simple calculation that reveals that a typical worker must work and contribute to the system for at least 25 years, earning a salary equivalent to three and a half times the minimum wage during that period, and that the accumulated savings must yield a minimum of 12% annually with bimonthly composition. In contrast, the average historical rate of return of SIEFOREs is in the order of 7%, making the accumulation of a large proportion of the population unlikely to be enough upon retirement. Only an estimated 12% of the workers who contribute to the defined-contribution system will have enough accumulation to exceed the minimum guaranteed pension offered by the government. These conclusions must be considered when any proposal to reform the system is discussed. Evidently, the system needs an urgent revision that increases the accumulation rate for workers, employers, and the government.

Lastly, Santillán-Salgado et al. (2016) develop a study that analyzes SIEFOREs' performance since the defined-contribution system's original introduction and through different time subperiods (1997–2012, 2004–2012, and 2008–2012). They present the results of an econometric analysis conducted on yields and the volatility of the five Basic SIEFOREs (SB1, SB2, SB3, SB4, and SB5) created by the Mexican government to replace the defined-benefit system, which prevailed until 1997, and that are listed on the Mexican Stock Exchange. Their main objective is to verify the nature of the stochastic behavior of the performance and volatility series of the different SIEFOREs. Specifically, they propose two working hypotheses to determine the presence of long-term memory effects in both series: (a) "It is possible to model the yields of SIEFORES without considering the long-term memory," and (b) "It is possible to model the volatilities of SIEFORES without considering the long-term memory." Both hypotheses are soundly rejected by the analysis, and the reported results show evidence of fractional integration in both the yields and the volatility series. In the first case, the analysis is extended with ARFIMA models (p, d, q). The presence of high-persistence volatility is also confirmed, justifying the development of GARCH models with fractional integration, known as FIGARCH (p, d, q) models. The authors report that there are great similarities between SB3, SB4, and SB5 return volatility. It is evident that the turbulence that surged during 2008 and the first months of the following year related to the global financial crisis, as well as the new phase of uncertainty associated with the risk that Greece, Portugal, Ireland, and Spain could default on their sovereign debt in 2011, had an impact on all three newer SIEFOREs, whose portfolios incorporate greater-risk assets. The main implication of these findings is that in order to measure the long-term performance of SIEFOREs and to model their volatility (with, for example, risk management purposes), more elaborate econometric models are needed. The use of modern econometric techniques for the measurement and modeling of yields and volatility is of the highest importance to determine the levels of exposure and to design possible risk coverage strategies that will prevent patrimonial damages to Mexican workers.

This literature review did not find any other contributions that analyze the relationship of performance and risk dimensions of defined-contribution pension funds, confirming the opportunity to make original studies that will improve our understanding of how these systems work and how they can be improved, more so considering the important economic and social role they play in modern societies.

18.3 The Defined-Contribution System in Mexico

As mentioned before, in 1997, Mexico implemented a defined-contribution system to replace the *pay-as-you-go* scheme, which had prevailed since the second half of the twentieth century. Originally, the system was created for workers of the Mexican Social Security Institute (Instituto Mexicano del Seguro Social (IMSS)).[3] In 2008, it included the State Workers Social Security and Safety Institute (Instituto de Seguridad y Servicios Sociales para los Trabajadores del Estado (ISSSTE)). While the new pension system includes most of the formal active workers in the country, it still coexists with defined benefits or traditional pension systems.[4] Nevertheless, the current tendency is for all pension systems to evolve progressively to defined contribution systems, managed privately through individual account schemes.

The traditional pension system has been managed by the IMSS since 1943, as a *funded* system created with active workers' contributions, in such a way that once the workers retire, their pensions could be financed through the fund. This reserve mechanism functioned when the number of pensioned workers represented a small ratio with respect to the total active workers. Demographic factors and social security pension requirements, which significantly favored the workers in detriment of the funds,[5] and their deficient management—channeling significant amounts of money to finance other services for the workers, such as health services—contributed to making fund revenues insufficient to cover pensions. This situation caused the

[3]This Social Security Institute embraces most of the formal active workers in the country.

[4]Pension scheme offered by state-owned companies such as the Federal Electricity Committee (Comisión Federal de Electricidad, CFE), Mexican Petroleum Company (Petróleos Mexicanos, PEMEX), several state governments and the Mexican Army.

[5]For instance, allowing workers to retire too early, and therefore receiving a pension for long periods of time.

depletion of fund reserves and forced authorities to substitute the funded scheme with a *pay-as-you-go* system, where pensions are paid directly with contributions from active workers. Nevertheless, after functioning for some years, this scheme also showed imbalances between contributions and benefits received by pensioned workers, due to an aging population, and a reduced mortality rate, which made the ratio between pensioned and active workers increase and, therefore, the funded system unsustainable.

Around 1995, the IMSS forecasted that if pension systems continued unchanged, the balance between revenues and pensions could only be maintained until 2005. From that date on, the pension system would face a fast-growing deficit, which eventually would have to be covered with federal revenues, and around 2020 would become too expensive to finance. Even though there were different opinions about the size of the deficit from both the Social Security Institute and external analysts, they all agreed that if the defined-benefit scheme remained the same, it would hardly be feasible for more than 20 years without incurring heavy social costs (Espinosa-Vega and Yip 2002).

These considerations led to the replacement of the *pay-as-you-go* retirement pension system with a defined-contribution scheme. As explained before, under this new system, workers, employers, and the government deposit their contributions for at least 25 years in an individual account where savings by or on behalf of the workers are kept and managed privately by companies specialized in pension funds (Administradoras de Fondos para el Retiro, AFORE), so upon their retirement, workers can finance their pensions themselves. Under this system, each worker will create his or her own fund, and the accumulated amount before retirement will depend on the size of the contributions and the length of time during which they are made.[6] Additionally, the government will guarantee a minimum pension in cases where the worker has failed to save enough to finance his/her retirement. A significant factor that will impact the accrued amount in individual accounts will be the financial market conditions during the accumulation period, since contributions are channeled by pension fund managers to invest in a wide variety of financial securities.

The new pension system closely resembles the defined-contribution system prevailing in Chile. Even international institutions, such as the World Bank and the International Monetary Fund, consider the Chilean experience as a reference in this matter. Nevertheless, the reform made in the Chilean pension system in 2008 and the problems it currently faces have brought to light some flaws.

[6]The length of time during which savings are deposited in individual accounts is known as the accumulation period.

Table 18.1 Different types of pension funds (SIEFORE) (July 2011)[a]

Type of SIEFORE	Worker's age range
Basic 1	60 years old or more
Basic 2	From 46 years to less than 60 years old
Basic 3	From 37 years to less than 46 years old
Basic 4	From 27 years to less than 37 years old
Basic 5	Less than 27 years old

Source: Modifications to the Investment Regime (2011), CONSAR
[a]Modifications can be found in *Disposición de carácter general que establecen el Régimen de Inversión al que deberán sujetarse las SIEFORE*, published in the Mexican Federal Gazette (Diario Oficial de la Federación DOF) on July 27, 2011. These amendments are also known as *Circular Única Financiera* o CUF (Unique Financial Amendment)

Table 18.2 Types of SIEFORE (from October 2012)[a]

Type of SIEFORE	Worker's age range
Basic 1	60 years old or more
Basic 2	From 46 years to less than 60 years old
Basic 3	From 37 years to less than 46 years old
Basic 4	Less than 37 years old

Source: Modifications to the Investment Regime (2011), CONSAR
[a]According to the *Disposición de carácter general que establecen el Régimen de Inversión al que deberán sujetarse las SIEFORE*, published in the Mexican Federal Gazette on October 12, 2012. On November 23, BS4 and BS5 were merged

18.3.1 Types of Pension Funds and Main Characteristics

Retirement pension funds are designed for workers with different age ranges to encompass the complete life span of active workers, as shown in Table 18.1.

During the last semester of 2012, two new and very significant modifications to the investment policies were carried out. One of these amendments was the merger of Basic SIEFOREs 4 and 5, under the premises that the number of workers in the SB5 had decreased and that investment limits were practically the same for both types of funds, with the exception of securitized titles. Therefore, only four types of SIEFORE remained, as shown in Table 18.2.

The other modification concerned only the SIEFORE Básica 1 (SB1[7]). In this type of SIEFORE (Table 18.3), accumulated savings serve two different purposes: payment of pensions and accumulation of savings. So in order to separate both investment strategies included in SB1, a new SIEFORE to manage pensions was authorized. This new type of fund started in 2016, when the resources accumulated

[7]This SIEFORE caters to workers more than 60 years old, or to younger workers who freely choose this type of pension fund.

Table 18.3 Types of Basic SIEFORE (from December 2015)[a]

Type of SIEFORE	Worker's age range
BS0	60 years old or more nearing a total pension withdraw or with a negative pension
BS1	60 years old or more (still in the accumulation phase)
BS2	From 46 years old to less than 60 years old
BS3	From 37 years old to less than 46 years old
BS4	Less than 37 years old

Source: Modifications to the Investment Regime (2015), CONSAR
[a]According to *Disposición de carácter general que establecen el Régimen de Inversión al que deberán sujetarse las SIEFORE* published in the Mexican Federal Gazette on septiembre 24, 2015

became large enough to separate it from SB1, allowing SB1 to keep the savings of workers aged 60 or more years that are still in the accumulation period. The new fund will manage the savings of pensioned workers or from workers entitled to a guaranteed minimum pension. The objective of this modification is to ease and to improve the management of savings that are still in the accumulation phase while protecting retired workers whose savings are managed by AFOREs.

18.3.2 Investment Regime for Basic SIEFOREs

The purpose of the investment regime amendments is to allow workers to access securities that may yield high returns and to reduce the funds' risk through diversification.

The investment regime amendment carried out on April 30, 2004, allowed the division of SB1 into two, thus generating SIEFORE Básica 2 (SB2). Under this modification, SB1 was considered to be a mandatory fund, and each AFORE must manage at least one pension fund of this type. Due to this constraint, SB1 must be made up of securities that maintain workers' purchasing power. As mentioned before, until July 2011, SB1 targeted workers 56 years old or older, or younger workers who chose this type of pension fund because they did not want to assume high risks. During its first years, SB1 included only government and private securities. The incorporation of foreign securities was allowed as long as they did not exceed 20% of total assets. Even though the amendment published on December 10, 2002, approved investments in international securities, the 2002 amendment to buy international assets could not be enforced until the 2004 investment regime reform was implemented.

SB1 was also required to maintain at least 51% of total assets in debt securities with a face value in investment units[8] (UDIs) or Mexican pesos and interest rates the same as or higher than fluctuations in UDIs or than the national consumer price index. Also, SB1 can incorporate up to 100% of net total assets in debt securities with triple A investment grade or equivalent or up to 5% in debt securities with investment grade A. They can also operate with derivatives, as long as the maximum limits for debt securities with triple A, double A, and A investment grades are maintained, according to the underlying asset nature. SB1 can buy debt assets, both domestic and foreign, directly or indirectly through investment vehicles, as long as established limits are observed.

It is forbidden to buy debt securities, both domestic and foreign, that do not comply with the aforementioned investment grades. Buying foreign securities that grant rights or returns linked, directly or indirectly, to individual stocks, to a group of stocks or to price fluctuations of assets, or to commodities other than those authorized, is not allowed either.

Table 18.4 shows the limits established for different investment securities, considering market, credit, and concentration risks, as well as conflicts of interest according to the 2007 amendment. To date, SB1 continues to be the most conservative pension fund.

Investment regime modifications in 2011 included an increase in equity limits, with up to 5% of equity in Basic SIEFORE 1, and an increase in value at risk (VaR) limits, as shown in Table 18.5. Also, investments in commodities[9] were authorized, to serve as a natural hedge against inflation and to link this type of assets to the real economy, besides their association with financial markets.[10] However, these financial securities are forbidden for SB1, as well as structured securities of different types, such as infrastructure, housing, and other types of projects.

After 2011 structured securities limits in BS1 increased from 0% to 10% and the amount allowed for securitizations increased for all the Basic SIEFORE in 5%. The conditional value at risk (CVaR) is introduced as an additional measure of risk. In general, from 2011 to 2017, the total number of risky securities allowed in all types of pension fund increased. In some cases, the ranking of financial instruments

[8]"Mexico's Investment Units (UDIS) are units based on price increases and are used to settle mortgage obligations or commercial acts. They were created in 1995 to protect banks and focused mainly on mortgage loans. Banco de México publishes the value in pesos of the Mexico's Investment Unit for each day of the month in the Official Federal Gazette. On the tenth day of each month at the latest, Banco de México publishes the value of the Mexico's Investment Unit corresponding to days 11 and 25 of the month, and on the 25th of each month at the latest it publishes the value corresponding to the 26th day of that month through to the tenth day of the following month". Source: Banco de México.

[9]Commodities may be understood as gold, silver and platinum through the investment vehicles authorized by the Risk Analysis Committee, (Comité de Análisis de Riesgos, CAR), or the underlying assets in derivates used in the Banco de México operations that serve as commodities but that are different to those underlying financial assets, such as equity, interest rate, exchange rates, investment units and credits, among others.

[10]Annual Performance Report (Informe Anual de Labores) (2011).

Table 18.4 Investment regime (according to the 2007 investment regime amendment)

Type of risk	Origin	Concept	Limit by typo of Basic SIEFORE			
			1	2	3	4
Market risk		Value at risk (historical VaR)	0.60%	1.00%	1.30%	1.60%
		Equity (through stock indexes)	0%	15%	20%	25%
		Foreign currency (dollar, euros, yens, and currency index securities)	30%	30%	30%	30%
		Derivatives	Yes	Yes	Yes	Yes
Credit risk		Debt securities mxAAA and government debt securities	100%	100%	100%	100%
		Debt securities mxAA- and government debt securities	50%	50%	50%	50%
		Debt securities mxAAA and government debt securities	20%	20%	20%	20%
Risk by issuers and/or counterparties	Local	Debt securities mxAAA from one issuer or counterparty	5%	5%	5%	5%
		Debt securities mxAA from one issuer or counterparty	3%	3%	3%	3%
		Debt securities mxA from one issuer or counterparty	1%	1%	1%	1%
		Debt securities mxBBB+ from one issuer or counterparty	5%	5%	5%	5%
		Debt securities mxBBB- from one issuer or counterparty	3%	3%	3%	3%
	Foreign	Foreign securities A- from one issuer or counterparty	5%	5%	5%	5%
		From only one issuer	20%	20%	20%	20%
Other limits		Foreign securities (debt securities, mínimum A-)	20%	20%	20%	20%
		Securitizations	10%	10%	10%	10%
		Structured securities and subordinated debt	0%	0%	0%	0%
		FIBRAS (infrastructure and housing)	0%	0%	0%	0%
		Inflation-protected securities	(51% min)	No	No	No
Conflicts of interest		Securities by related entities	15%	15%	15%	15%
		Securities by entities with patrimonial affiliation with the AFORE	5%	5%	5%	5%

Source: Financial Data, Investment Regime (2007), CONSAR

Table 18.5 Investment regime (according to the 2011 investment regime amendment)

Type of risk	Origin	Concept[a]	Limit by typo of Basic SIEFORE[b]			
			1	2	3	4
Market risk		Value at risk (one-day historical VaR)[c]	0.70%	1.10%	1.40%	2.10%
		Equity (through stock indexes)[d, e]	5%	25%	30%	40%
		Foreign currency (dollar, euros, yens, and currency index securities)[f]	30%	30%	30%	30%
Risk by issuers and/or counterparties	Local	Ordinary debt from mxAAA to mxAAA or foreign currency from BB to AAA	5%	5%	5%	5%
		Subordinated debt from mxBB+ to mxBBB+ or foreign currency from B+ to BB-	1%	1%	1%	1%
	Foreign	Foreign securities A- from one issuer or counterparty	5%	5%	5%	5%
		From only one issuer[g]	--- maximum (35%, $300 mdp) ---			
Other limits		Foreign securities	20%	20%	20%	20%
		Securitizations[h]	10%	15%	20%	30%
		Structured securities[i]	0%	15%	20%	20%
		Infrastructure or housing	0%	10%	13%	13%
		Other	0%	5%	7%	7%
		Inflation-protected securities[j]	(51% min)	No	No	No
		Commodities	0%	5%	10%	10%
Conflicts of interest		Securities by related entities	15%	15%	15%	15%
		Securities by entities with patrimonial affiliation with the AFORE[k]	5%	5%	5%	5%
Mandates and contracts		Investment mandates	Yes	Yes	Yes	Yes
		Mutual funds	Yes	Yes	Yes	Yes
		Derivatives	Yes	Yes	Yes	Yes

Source: Financial Data, Investment Regime (2011), CONSAR

[a]As a percentage of assets directly managed by the SIEFORE

[b]Todos los límites son porcentajes máximos, excepto el límite de protección inflacionaria

[c]As total percentage of the SIEFORE, including assets managed by mandates or mutual funds

[d]Includes individual equity, IPOs, national equity and foreign indexes, and mandatory convertible securities in equity from national issuers

[e]Medium- and long-term issues, issuer, and collateral ratios. Repos and derivates are considered within this limits

[f]It includes all asset holdings by Basic SIEFORE managed by the same AFORE, to national and foreign debt and to structured securities. This limit maybe exceeded by CKDs (Capital Development Certificates) if they comply with the investment regime limits

[g]Securitization issued by an independent agent that ensure that investment regime guidelines are considered with these limits

[h]ICKDs and FIBRAS are included. Structured securities are divided in two: (1) infrastructure and housing and (2) other (private capital)

[i]Maximum limits for inflation-protected securities that guarantee an equal or higher return rate than inflation rate in Mexico

[j]Limit established in SAR Law, Article 48, fraction 10. Exceptionally a 10% is permitted. The limit is 0% when there are securities by entities with patrimonial affiliation

[k]All refer to maximum limits, with exception to inflationary protection, which refers to a minimum

included in the funds decreased, as it was the case of some foreign securities that changed their grade fromt A- to BBB-.

In 2013, REITs (real estate investment trusts) were introduced, but they did not account for the VaR as risky securities. Also, commodity derivatives were introduced.

In 2016, CERPIs and FIBRAE were introduced. CERPIs are certificates that allow investors to have access to a wide range of economic productive sector projects, and FIBRAEs are REITs for mature projects on energy and infrastructure sectors.

Eventually, on January 5, 2018, the amendment published in the Mexican Federal Gazette allowed pension funds to invest in foreign REITs and mutual funds with active strategies so they may beat the market. Also, ETS were introduced in the SIEFOREs' portfolios to track index funds (both national and foreign), as well as SPACs (special purpose acquisition companies). These certificates serve as an alternative equity designed to purchase companies with growth potential; nevertheless, these may turn out to be very risky if the enterprises do not grow as expected. In Table 18.6, modifications to the investment regime in 2018 are shown.

18.3.3 Pension Funds Behavior

The behavior of Basic SIEFORE through time is observed in Graph 18.1. The cumulative index of the funds are shown, as well as their returns. BS1 index grew with certain stability until the middle of 2008, when a large crash due to the 2008–2009 international market crisis is observed. After this period, BS1 tends to increase again; nevertheless, this growth stopped in 2014, and it was followed by a period of increased volatility, as it is shown in the SB1 return graph. The same behavior is observed in BS2. BS3 and BS4 show the same trend; nevertheless, BS4 grew at a faster pace than BS3, and therefore the volatility of the latter is higher than that of SB3.

18.3.4 Descriptive Statistic Parameters

Like many financial time series, the returns of pension funds and their volatility, measured through the price index, present some stylized facts such as leptokurtic distributions with heavy tails and volatility clusters.[11] The main descriptive statistic parameters from the returns of the Basic SIEFORE are shown in Graph 18.2.

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[11]Mandelbrot (1963) was the first to notice the presence of volatility clusters while studying cotton prices, observing that large fluctuations are followed by large fluctuations, while small changes tend to be followed by small changes. Fama (1965) found similar results while analyzing 30 stocks belonging to the Dow Jones Index.

Table 18.6 Investment regime I (according to the 2018 investment regime amendment)

Type of risk	Origin	Concept[a]	Limit by typo of Basic SIEFORE 1	2	3	4
Market risk		Value at risk (one-day historical VaR)[b]	0.70%	1.10%	1.40%	2.10%
		Difference of the conditional value risk[b]	0.30%	0.45%	0.70%	1.00%
		Liquidity coverage ratio[c]	80%	80%	80%	80%
Risk by issuers and/or counterparties[d]		Debt issued or endorsed by the federal government	100%	100%	100%	100%
	Local[e]	SPE[e] debt from mxBBB to mxAAA or int'l currencies BB to AAA	10%	10%	10%	10%
		Debt from mxBBB to mxAAA or int'l currencies BB to AAA	5%	5%	5%	5%
		Subordinated debt mxBB+ to BBB- or int'l currencies B+ to BB-BB-	1%	1%	1%	1%
		Hybrid debt from mxBBB+ to mxBBB or int'l currencies BB+ to BB	2%	2%	2%	2%
	Foreign	Foreign securities from BBB to AAA from one issuer or counterparty[f]	5%	5%	5%	5%
		From only one issuer[g]	--- maximum (35%, $300 mdp) ---			
Asset class limits		Foreign securities[d]	20%	20%	20%	20%
		Equity[d,i]	10%	30%	35%	45%
		Foreign currency[d]	30%	30%	30%	30%
		Securitizations[d,i]	10%	15%	20%	30%
		Structured securities[d,j]	10%	15%	20%	20%
		Mexican REITs (FIBRAS) and REITs[k]	5%	10%	10%	10%
		Inflation-protected securities[l]	(51% min)	No	No	No
		Commodities	0%	5%	10%	10%
Conflicts of interest		Securities by related entities	15%	15%	15%	15%
		Securities by entities with patrimonial affiliation with the AFORE[m]	5%	5%	5%	5%
Vehicles and derivatives		Investment mandates	Yes	Yes	Yes	Yes

(continued)

Table 18.6 (continued)

Type of risk	Origin	Concept[a]	Limit by typo of Basic SIEFORE			
			1	2	3	4
		Derivatives	Yes	Yes	Yes	Yes

Source: Financial Data, Investment Regime (2018), CONSAR

[a]All the limits are maximum percentages, with the exception of the inflation protection limits

[b]As a percentage of the assets under management (AUM) directly managed by the SIEFORE. VaR will no longer be a regulatory limit once the AFORE satisfies the criteria set up in the Financial Provisions (CUF). The limits of the difference of the conditional VaR were determined by the Risk Analysis Committee (CAR), which might be stricter than the limits set up in the Investment Regime Provisions

[c]As a percentage of the high liquid assets of the SIEFORE. It is defined as the ratio between the value of the SIEFORE's reserves for derivative exposure and the value of high liquid assets

[d]As a percentage of the total AUM of the SIEFORE, including the assets managed by the specialized investment manager (Mandatario in Spanish)

[e]Rating of medium- and long-term issuances, as well as the issuer and/or endorser, in corresponding proportion. Repos and derivatives are computed in these limits as well. SPE stands for state productive enterprises

[f]The regulation permits investments in foreign securities with a credit rating below A- and equal or greater than BBB-. Nevertheless, the AFORE must abide by the Investment Regime Provisions and the Financial Provisions (CUF)

[g]Applies to the asset holdings of all pension funds of the same fund manager (AFORE) and for debt and structured securities. A CKD may exceed this limit if the issue meets certain conditions

[h]Includes individual stocks, IPOs, domestic and international equity indexes listed in the Index Lists, and mandatory convertible debt into share from Mexican issuers

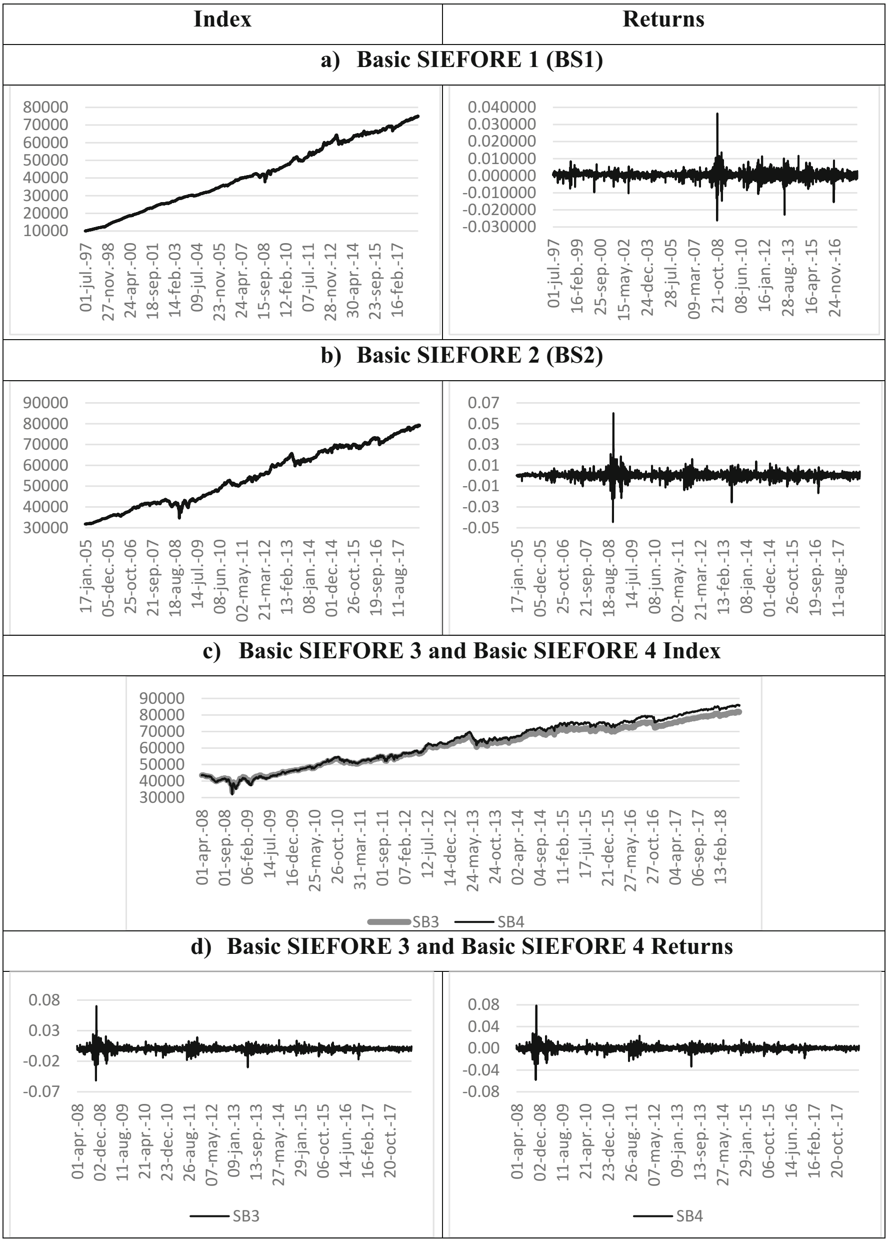
[i]Securitizations fulfilling criteria established in Appendix R of the Financial Provisions (CUF) are computed in these limits and are considered as being issued by an independent issuer, as well as certificates that the source of income comes from real assets

[j]Includes CKDs and CERPIs

[k]Includes Mexican REITs (FIBRAS) and FIBRA-E. The latter is an issuer trust whose resources will be allocated for direct or indirect investment in companies, projects, or energy assets or infrastructure

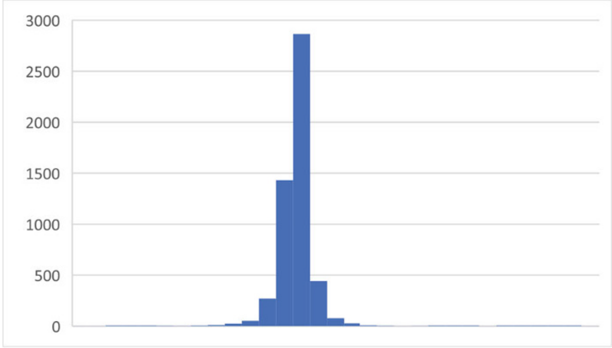
[l]Minimum investment limit in securities that ensures a return equal or greater than the inflation rate in México

[m]The limits are written down in the SAR Law, Article 48, paragraph X. In exceptional cases, it could be increased up to 10%. The limit is 0% for financial entities with patrimonial affiliations



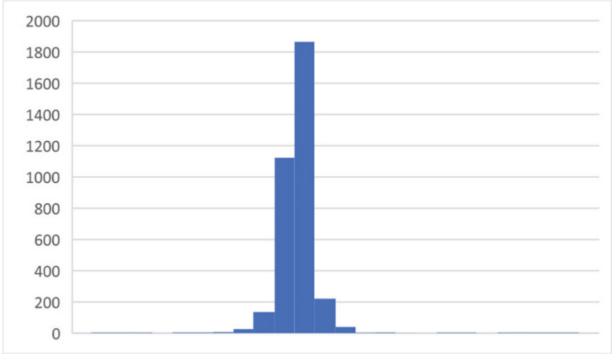
Graph 18.1 Basic SIEFORE cumulative index and returns. (*Source:* Prepared by the authors)

a) Basic SIEFORE 1



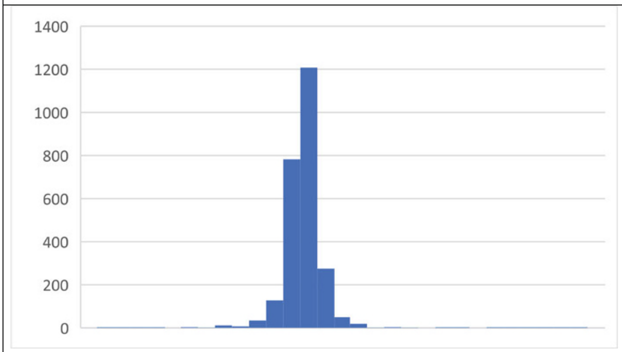
Observations	5241
Mean	0.000383
Median	0.000461
Maximum	0.036453
Minimum	-0.026253
Std. Deviation	0.002059
Skewness	0.191647
Kurtosis	39.69287
Jaque-Bera	294044.9

b) SIEFORE 2



Observations	3341
Mean	0.000272
Median	0.000332
Maximum	0.060016
Minimum	-0.044505
Std. Deviation	0.003538
Skewness	0.758445
Kurtosis	44.82566
Jaque-Bera	243849.4

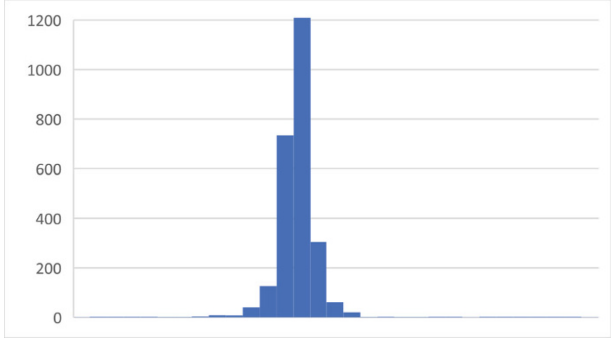
c) Basic SIEFORE 3



Observations	2536
Mean	0.000249
Median	0.000347
Maximum	0.070234
Minimum	-0.051552
Std. Deviation	0.004551
Skewness	0.782195
Kurtosis	39.48468
Jaque-Bera	140914.8

Graph 18.2 Descriptive statistic of the returns. (*Source*: Prepared by the authors)

d) Basic SIEFORE 4



Observations	2536
Mean	0.000268
Median	0.00037
Maximum	0.078758
Minimum	-0.058124
Std. Deviation	0.005219
Skewness	0.675916
Kurtosis	36.86099
Jaque-Bera	121347

Graph 18.2 (continued)

18.4 Methodological Issues

According to Ardia et al. (2016), given y_t, $\mathbb{E}(y_t) = 0, \mathbb{E}(y_t, y_{t-r}) = 0, r \neq 0, t > 0$, the Markov-switching GARCH (MS-GARCH) model can be written in a general way as

$$y_t|(s_t = k, \Omega_{t-1}) \sim \mathcal{D}_k(0, h_{k,t}, \Xi_k), \tag{18.1}$$

$\mathcal{D}_k(0, h_{k,t}, \Xi_k)$ is continuous zero-mean distribution, with time varying variance $h_{k,\, t}$ and shape parameters gathered into vector Ξ_k; s_t is a stochastic state variable with whole values, defined in the discrete space $\{1, \ldots, K\}$, whose evolution goes according to a nonobserved ergodic, first-order homogeneous Markov chain, whose transition probability matrix is defined as

$$\mathbf{P} \equiv \begin{pmatrix} p_{1,1} & \cdots & p_{1,K} \\ \vdots & \ddots & \vdots \\ p_{K,1} & \cdots & p_{K,K} \end{pmatrix}_{K \times K} \tag{18.2}$$

$p_{i,\, j} \equiv \mathbb{P}(s_t = j | s_{t\, -\, 1} = i)$ is transition probability; $0 < p_{i,\, j} < 1\ \forall\ i, j \in \{1, \ldots, K\}$; $\sum_{j=1}^{K} p_{i,j} = 1, \forall i \in \{1, \ldots, K\}$. $\Omega_{t\, -\, 1} \equiv \{y_{t\, -\, i}, i > 0\}$ is the information set observed up to the previous period and, according with $\mathcal{D}_k(\cdot)$,

$$\mathbb{E}[y_t^2 | s_t = k, \Omega_{t-1}] = h_{k,t}; \tag{18.3}$$

$h_{k,\, t}$ is the variance of y_t conditional on $s_t = k$. Following Haas et al. (2004), $h_{k,\, t}$ is conducted by a GARCH process; i.e., the variance is conditioned by the regime or state, being a dependent function of the past realizations of y_t, past variances, and a vector of parameters that in turn depends on the regime:

$$h_{k,t} \equiv h(y_{t-1}, h_{k,t-1}, \Theta_k), \tag{18.4}$$

$h(\cdot)$ is a measurement function that defines the filter for the conditional variance ensuring nonnegativity.

The Bollerslev (1986) GARCH model is

$$h_{k,t} \equiv \alpha_{0,k} + \alpha_{1,k} y_{t-1}^2 + \beta_k h_{k,t-1}, k = 1, \ldots, K. \tag{18.5}$$

$\Theta_k = (\alpha_{0,\ k}, \alpha_{1,\ k}, \beta_k)'$, $\alpha_{0,\ k} > 0$, $\alpha_{1,\ k} > 0$, $\beta \geq 0$ and $\alpha_{1,\ k} + \beta_k \leq 1$ are required, respectively, to ensure that the variance in each regime is covariance-stationary and strictly positive.

The MS-GARCH model is complete with the conditional distribution of $\eta_{k,t} \equiv y_t / h_{k,t}^{1/2} \sim iid\mathcal{D}_k(0, 1, \Xi_k)$ for each regime. The normal probability density function is given as

$$f_N(\eta) \equiv \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\eta^2}, \quad \eta \in \mathbb{R}. \tag{18.6}$$

On the other hand, the probability density function of a variable distributed as a t-Student variable is given by

$$f_t(\eta; \nu) \equiv \frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\sqrt{(\nu-2)\pi\Gamma\left(\frac{\nu}{2}\right)}} \left(1 + \frac{\eta^2}{(\nu-2)}\right)^{-\frac{\nu+1}{2}}, \quad \eta \in \mathbb{R}. \tag{18.7}$$

If $y \equiv (y_1, \ldots, y_T)'$ is the vector containing all the observations and $\Psi \equiv (\Theta_1, \Xi_1, \ldots, \Theta_K, \Xi_K, \mathbf{P})$ is the parameters set, then we have the likelihood function

$$\mathcal{L}(\Psi | y) \equiv \prod_{t=1}^{T} f(y_t | \Psi, \Omega_{t-1}), \tag{18.8}$$

$$f(y_t | \Psi, \Omega_{t-1}) \equiv \sum_{i=1}^{K} \sum_{j=1}^{K} p_{i,j} z_{i,t-1} f_{\mathcal{D}}(y_t | s_t = j, \Psi, \Omega_{t-1}).$$

$z_{i,\ t\ -\ 1} \equiv \mathbb{P}(s_{t\ -\ 1} = i | \Psi, \Omega_{t\ -\ 1})$ is the filtered probability of being in the state i in $t - 1$, which is obtained through the Hamilton filter (Hamilton 1989, 1994). If such is the case, $\widehat{\Psi}$, the vector of parameter of the model can be estimated by maximum likelihood methods.

Table 18.7 SB1 MS-GARCH models

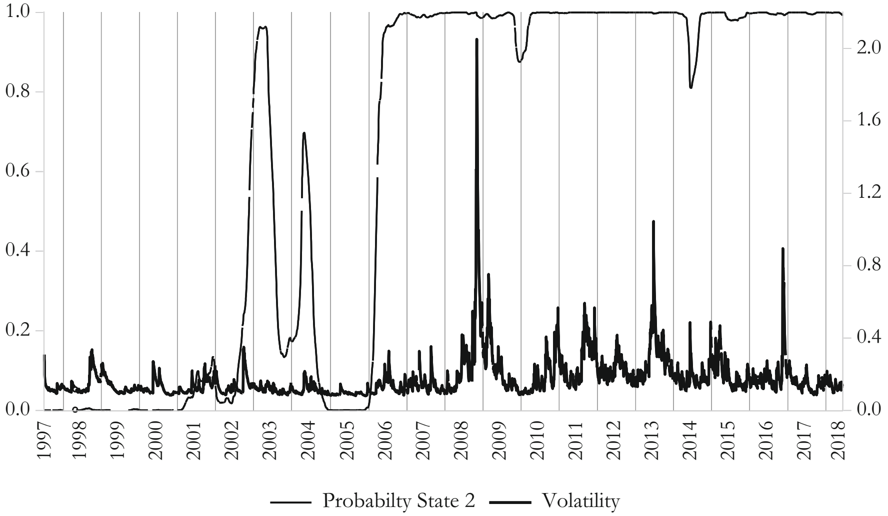
	Normal	S-normal	t	$S-t$
$\alpha_{0,1}$	0.0001[a]	0.0001[a]	0.0002[b]	0.0004[a]
$\alpha_{1,1}$	0.0294[a]	0.0311[a]	0.0400[b]	0.0620[c]
β_1	0.9479[a]	0.9454[a]	0.9500[a]	0.9258[a]
ν_1			2.8196[a]	2.8155[a]
ξ_1		0.9793[a]		0.8988[a]
$\alpha_{0,2}$	0.0085[a]	0.0084[a]	0.0007[a]	0.0009[b]
$\alpha_{1,2}$	0.1718	0.1890	0.1810	0.1729
β_2	0.8262[a]	0.8087[a]	0.8188[a]	0.8207[a]
ν_2			6.0780[a]	6.7780[a]
ξ_2		0.8326[a]		0.9921[a]
$p_{1,1}$	0.9509[a]	0.9414[a]	0.9986[a]	0.9986[a]
$p_{2,1}$	0.2738[a]	0.3127[a]	0.0006	0.0009
p_1	0.8480	0.8421	0.3024	0.3914
p_2	0.1520	0.1579	0.6976	0.6086
Logl	2866.1875	2873.0456	2946.9992	2959.9666
AIC	−5716.3750	−5726.0911	−5873.9985	−5895.9331
BIC	−5663.8152	−5660.3914	−5808.2987	−5817.0934

[a, b, c]respectively, 1%, 5%, and 10% significance level

18.5 Analysis of Mexican Retirement Pension Fund Volatility

Table 18.7 reports the estimated parameters for SB1 two-regime volatility under four specifications: errors following distributions, normal and Student's t, and their corresponding skewed versions for both cases. Roughly speaking, almost all the parameters of all the estimated SB1 models look very similar. Nevertheless, when the two information criteria (Akaike and Bayesian) are taken into account, the studentized distribution options are the preferred specifications, especially the skewed one. The same conclusion is reached according to the log value of the maximum likelihood function. Considering both the nonskewed and the skewed t-Student models, the estimated parameters for the two regimes suggest that SB1 volatility can be regarded as a highly persistent process in a regime, accompanied by a less persistent volatility regime due to the nonsignificant (zero) squared past error coefficient shown by the four estimated models. At the same time, through the skewed estimated model, we can observe that the less persistent volatility regime corresponds to the more skewed period. The half-life of the volatility in the first regime is about 56 days, while for the second regime it is around 3.5 days.[12] The estimated probability of remaining at state 1 after being there is high in all the cases,

[12]The half-life of the volatility, i.e., the time that volatility takes to revert half of the way toward its unconditional mean after a deviation from the same, was estimated as usually: $\ln(0.5)/\ln(\alpha_{1,k}+\beta_k)$.



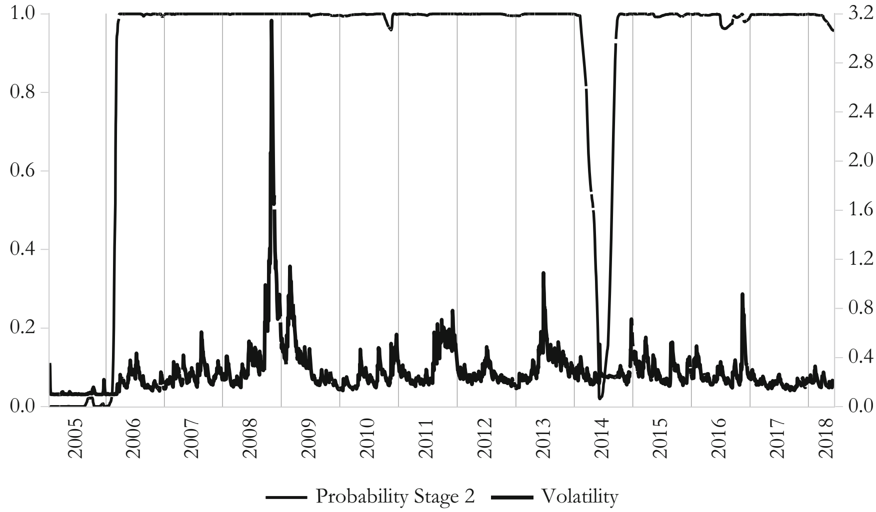
Graph 18.3 SB1 volatility and state 2 smoothed probabilities

Table 18.8 SB2 MS-GARCH models

	Normal	S-normal	t	$S-t$
$\alpha_{0,1}$	0.0001[a]	0.0001[a]	≈0	≈0[b]
$\alpha_{1,1}$	0.0249[a]	0.0238[a]	0.0002	0.0806[a]
β_1	0.9562[a]	0.9572[a]	0.9997[a]	0.9193[a]
ν_1			2.7683[a]	5.7774[a]
ξ_1		0.9994[a]		1.0198[a]
$\alpha_{0,2}$	0.0104[a]	0.0093[a]	0.0020[b]	0.0086[a]
$\alpha_{1,2}$	0.1782	0.1791	0.1468[c]	0.3687
β_2	0.8211[a]	0.8199[a]	0.8397[a]	0.6209[a]
ν_2			7.1128[a]	11.6205[b]
ξ_2		0.8826[a]		0.6853[a]
$p_{1,1}$	0.9327[a]	0.9247[a]	0.9960[a]	0.7844[a]
$p_{2,1}$	0.1702[a]	0.1698[a]	0.0007	0.5875[a]
p_1	0.7167	0.6927	0.1565	0.7316
p_2	0.2833	0.3073	0.8435	0.2684
Logl	58.0083	61.9199	84.2557	79.6442
AIC	−100.0166	−103.8399	−148.5114	−135.2884
BIC	−51.0352	−42.6132	−87.2847	−61.8164

[a, b, c] respectively, 1%, 10%, and 5% significance level

more so in the studentized specifications, where it looks almost like an absorbent state. Nonetheless, the estimated state probabilities suggest fair odds to alternate into states.



Graph 18.4 SB2 volatility and state 2 smoothed probabilities

As Graph 18.3 shows, a period characterized by lower volatility prevailed up to the middle of 2008. According to the estimated parameters of the MS-GARCH model with skewed t errors in both regimes, for almost all the years before 2006, a more skewed return distribution and a higher persistence level in volatility were observed. The notorious exception is the subperiod from the middle of 2002 to the last months of 2004, when both error distribution skewness and volatility persistence decreased. From 2006 to the end of the sample, Fig. 18.1 shows a general level of higher but less persistent volatility, accompanied by more skewed returns.

Table 18.8 shows the four estimated SB2 two-regime volatility models. We can see a few differences in some of the estimated parameters, but the Akaike and Schwarz criteria, and the value of the log-likelihood function, now suggest that the *t*-Student specification fits the data better. Nevertheless, it is worth noting that the skewness parameters estimated for the skewed normal and skewed-*t* specifications are highly significant. Under the assumptions of errors following a *t*-Student distribution in the two regimes, volatility seems very persistent, especially at the first state when it appears to correspond to an I-GARCH process, having a half-life of about 2310 days in the first regime and around 51 days in the second. Again, the probability of staying at state 1 is seen as an absorbent state, but the state probabilities suggest the possibility of switching from one regime to another.

Comparing the SB2 volatility shown in Fig. 18.2 with the aforementioned SB1 volatility, a similar pattern is observed for the common period. Before 2006, the volatility level is lower throughout the analyzed period, initiating an escalation in the first months of 2006 and, at the same time, changing the volatility process to regime two, in which it stays for all the remaining time minus a few months in mid-2014 (Graph 18.4).

The estimated SB3 models, Table 18.9, also provided similar values for the relevant parameters. Akaike criterion and Schwarz Bayesian criterion point out

Table 18.9 SB3 MS-GARCH models

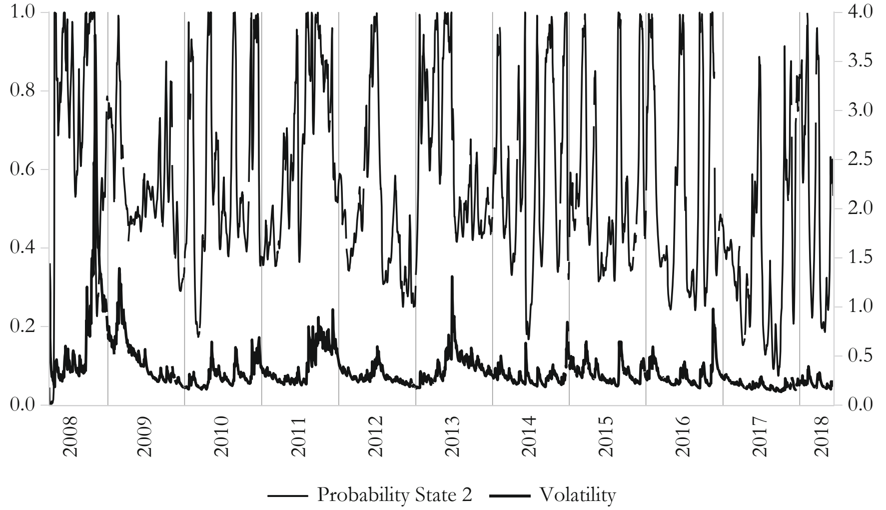
	Normal	*S*-normal	*t*	*S* − *t*
$\alpha_{0,1}$	0.0007[a]	0.0006[a]	0.0003[b]	0.0002[b]
$\alpha_{1,1}$	0.0271[b]	0.0266[b]	0.0177[b]	0.0172[b]
β_1	0.9464[a]	0.9471[a]	0.9625[a]	0.9642[a]
ν_1			99.9836[a]	99.9826[a]
ξ_1		0.9745[a]		1.0323[a]
$\alpha_{0,2}$	0.0228[a]	0.0203[a]	0.0064[a]	0.0052[a]
$\alpha_{1,2}$	0.1643	0.1699	0.1600	0.1659
β_2	0.8297[a]	0.8249[a]	0.8380[a]	0.8327[a]
ν_2			6.8949[a]	7.2209[a]
ξ_2		0.8903[a]		0.8990[a]
$p_{1,1}$	0.9645[a]	0.9585[a]	0.9398[a]	0.9246[a]
$p_{2,1}$	0.1278[a]	0.1344[a]	0.0601[b]	0.0586[c]
p_1	0.7824	0.1344	0.4998	0.4371
p_2	0.2176	0.2362	0.5002	0.5629
Logl	−668.3394	−666.1323	−655.3594	−652.5671
AIC	1352.6788	1352.2646	1330.7188	1329.1341
BIC	1399.4796	1410.7656	1389.2198	1399.3354

[a, b, c]respectively, 1%, 5%, and 10% significance level

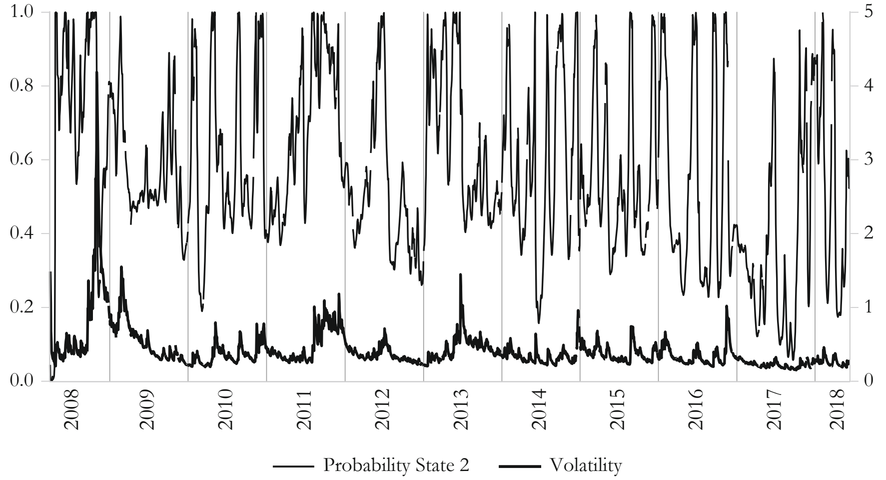
Table 18.10 SB4 MS-GARCH models

	Normal	*S*-normal	*t*	*S* − *t*
$\alpha_{0,1}$	0.0008[a]	0.0007[a]	0.0003[b]	0.0003[b]
$\alpha_{1,1}$	0.0310[b]	0.0302[b]	0.0176[b]	0.0166[b]
β_1	0.9433[a]	0.9444[a]	0.9637[a]	0.9655[a]
ν_1			99.9416[a]	84.3502
ξ_1		0.9585[a]		1.0179[a]
$\alpha_{0,2}$	0.0313[a]	0.0263[a]	0.0085[a]	0.0066[a]
$\alpha_{1,2}$	0.1790	0.1864	0.1563	0.1582
β_2	0.8158[a]	0.8095[a]	0.8414[a]	0.8401[a]
ν_2			6.9266[a]	7.3299[a]
ξ_2		0.8640[a]		0.8881[a]
$p_{1,1}$	0.9593[a]	0.9484[a]	0.9413[a]	0.9276[a]
$p_{2,1}$	0.1466[a]	0.1581[a]	0.0583[b]	0.0544[c]
p_1	0.7827	0.7539	0.4986	0.4288
p_2	0.2173	0.2461	0.5014	0.5712
Logl	−1046.0532	1042.2902	−1033.3296	−1029.5450
AIC	2108.1064	2104.5804	2086.6592	2083.0901
BIC	2154.9072	2163.0814	2145.1602	2153.2913

[a, b, c]respectively, 1%, 5%, and 10% significance level



Graph 18.5 SB3 volatility and state 2 smoothed probabilities



Graph 18.6 SB4 volatility and state 2 smoothed probabilities

different choices; the latter selects the *t*-Student model, while the former marginally prefers the skewed option. Since the maximized value of the log-likelihood function suggests the skewed-*t* model as the best fit, we will use it to continue the analysis. According to our model choice, we observe again a first regime with a highly persistent volatility process, which becomes notably less persistent in the second regime, simultaneously with a less skewed error distribution. The estimated half-life of the volatility for the first regime is about 37 days, but it is only around days for the second. The higher persistence period is also identified as the one with the more skewed error distribution. The probability of staying in the period of higher volatility persistence is a little lower than the previous cases. This, together with the state probabilities, suggests that the volatility process can switch from one regime to another more frequently, as can be seen in Fig. 18.3, which describes the behavior of the volatility and the smoothed probabilities for state 2 during the corresponding span of time. A similar pattern can be seen in Table 18.10 and Graph 18.5, which show, respectively, the estimated parameters of the four SB4 models and the behavior of the volatility and the state 2 smoothed probabilities (Graph 18.6).

18.6 Concluding Remarks

This chapter is devoted to the analysis of Mexican retirement pension funds' (SIEFOREs') volatility. The analysis is supported by a Markov-switching GARCH (MS-GARCH) model. In order to gain a better understanding of SIEFOREs' return volatility, we begin our study with a detailed description of the Mexican pension fund system.

Among the main factors that may have caused the volatility process of SB1 and SB2 to change from regime one to two in 2014 are the high levels of volatility in the international financial markets. This generalized increase in volatility was associated with the uncertainty surrounding interest rate increases by the Federal Reserve. Regarding the high volatility of SB3 and SB4, Greece's sovereign debt crisis and the uncertainty about what the consequences could be under a potential Brexit, and its conjunction with domestic economic circumstances, may explain it. After the 2008 financial crisis, SB3 and SB4 were characterized by high price return volatility due to the introduction of risky assets such as structured securities and REITs.

The increasing level of SB1 volatility is puzzling because this fund is the oldest one among those operating in the reformed Mexican pension fund system. Higher level of risk in pension fund returns are not good news for the people whose life after retirement depends on the balance accumulated as result of the yields provided by such pension funds. A natural claim is that the authorities should review the investment strategy scheme allowed by regulations and promote a better risk management. Constant performance appraisal of the pension funds is a must, heavily stressing the risk premia that are finally conveyed to the saver, that is, net of commissions and any other fees. As the analysis presented in this chapter suggests, similar advice could be applicable to the managers of the other SBs.

In general, the estimation of the MS-GARCH models shows that the volatility of Mexican pension fund returns is highly persistent, including levels that suggest explosive processes. Previous research has provided evidence of this fact and explains it as a consequence of the presence of long-memory processes, which, characterized by slowly decaying significant autocorrelations, pose several complications to understand and explain the behavior of the time series of financial asset returns because within the standard asset pricing theory, there is no satisfactory frame to explain financial asset volatility. The only way to learn more about the nature of SIEFOREs' return volatility is to continue exploring them with increasingly robust econometric models whose findings can be used by SIEFOREs' risk managers and protect the population's retirement savings while, at the same time, maximizing their accumulation.

Another subject of future studies is to improve our comprehension of the role of the restrictions that savers are forced to deal with. An outstanding restriction is that they cannot switch to another fund management company whenever they wish to, but they can only do so once a year. Studying if the fact that customers are, to some extent, captive as that restriction prevents pension fund managers from improving their performance because they are not subject to a real competitive challenge is another promising project.

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