Mexico's Petroleum Hedging Program as Counter-Cyclical Insurance

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A Note on Sourcing: Our team consulted a wide range of direct and indirect sources. We spoke with traders from multiple leading global investment banks who worked directly on the Hacienda Hedge, as well as academics and leading financial journalists who have written about the hedge. We are grateful for their contributions and insights. We are especially grateful for the pioneering work of Javier Blas on the history and origins of the Hacienda Hedge, and the insightful quantitative analysis of Ilia Bouchouev and his forthcoming book, *Virtual Barrels*.

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Executive Summary

The purpose of this brief is to provide analysis and insight into how Mexico has achieved counter-cyclical oil revenue stabilization, by way of the world's largest natural resource hedging program—widely referred to in financial circles as the "Hacienda Hedge." Further, we explore the possible relevance of this experience to other oil exporters in the region, including Brazil, and to exporters of critical minerals and other commodities central to the clean energy transition. We contextualize Mexico's hedging program in light of other natural resource strategies deployed in Latin America, examining why the Hacienda Hedge is an effective form of insurance against downturns in the price of oil, and how it has improved Mexico's credit rating and helped stabilize government spending. We do so by evaluating the strategy in light of twenty years of data, as well as a set of Monte Carlo simulations, as documented in the Technical Appendix. These simulations point to the possible stabilization effects and cash-flow positivity of such a strategy, across a range of hypothetical strike prices.

This report highlights three key lessons from the Hacienda Hedge:

1. **Simplicity:** The Hacienda Hedge is the largest natural resource hedge and yet consists of only puts, a strategy that provides transparent costs and robust insurance.
2. **Efficiency:** The hedge has been kept efficient by aggressively soliciting bids from multiple banks and varying deployment strategies to keep costs in line.
3. **Continuity:** The hedge is run annually without a view to a specific outcome, but rather as a continuous insurance program, to great success.

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Introduction

Oil is the world's most traded commodity. Oil prices fluctuate constantly and can be highly volatile. They are also actively responsive to global shocks and changes in macroeconomic conditions. Countries that rely on oil revenue thus face a dilemma: How to manage price shocks and stabilize revenue over time? Failure to do the latter can lead to forced austerity during price downturns as well as a decline in credit ratings.

There are many different strategies pursued globally to deal with this volatility. Some countries, like Norway, establish sovereign wealth funds to serve as state-owned investment vehicles. These need to be carefully run, requiring long term planning and expertise. Other countries, like Chile and Colombia, create rainy day funds to save oil revenue with an eye to future shocks. In practice, however, it can be hard for governments to avoid spending oil revenue on immediate expenses and for multiple political actors to agree on a consistent policy on when to spend rainy day funds. Countries could also sell oil futures to guarantee a floor on future revenue, but these introduce political risk, since they could involve forgoing a significant amount of revenue.

The Mexican government has created a successful, multi-decade solution to the volatility of oil prices. It hedges risk via the world's largest oil hedge, widely known in financial circles as "the Hacienda Hedge." "Hacienda" refers to the cabinet-level Secretaría de Hacienda y Crédito Público or the Secretariat of the Treasury and Public Credit, which is the federal government's finance ministry. The Hacienda team, in concert with other federal entities, has maintained the hedge consistently not in order to generate excess profits, but rather to stabilize oil export revenue. By purchasing a very large number of puts (options to sell oil at a fixed price in the future), the Mexican government buys insurance on the risk of a large decline in the price of oil.

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The Hacienda Hedge has helped the Mexican government navigate multiple global shocks, including the 2008 global financial crisis and the COVID-19 pandemic. Further, it has helped stabilize government revenue, avoid cuts to government services during declines in oil prices, and decrease national borrowing costs. All of these effects are estimated to have increased total aggregate consumption on a national level by nearly 1 percent.

The Hacienda team has successfully maintained this hedge for nearly twenty years, thereby insuring for all major shocks in the oil market, and improving both its fiscal picture and sovereign debt ratings. The success of the Hacienda Hedge offers many lessons for other governments to draw upon.

What is a Hedge? What is a Put?

The Mexican government hedges its oil risk through a large-scale program of buying put options via the Mexican Central Bank, and a smaller program via Pemex, the state-owned oil firm. Before exploring the use and impact of this hedge, we will define our terms and explain some core finance concepts.

In finance, a hedge is an attempt to offset risk in an asset or investment with financial instruments. As a large supplier of oil, the Mexican government faces the risk that prices could fall and forecasted revenue could come in much lower than expected. This is a realistic concern; oil prices are highly volatile and have fluctuated rapidly over the past twenty years in response to economic shocks. To deal with this risk, Mexico purchases a large basket of put options every year as a form of insurance: the Hacienda Hedge.

The basic building blocks of options are put options and call options. A put option is the right, but not the obligation, to sell something at a specified

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price (the strike price), at a specified future date range. A call option is the right, but not the obligation, to buy something at a specified price (the strike price) at a specified future date range. Puts are often sold with calls. For example, the Hacienda bought put options guaranteeing them the right but not the obligation to sell oil for $70 a barrel in 2009. When oil prices fell to $57 that year, it was able to offset the fall in market prices by exercising these put options and selling oil at $70 a barrel.

A critical element of a put option is that exercising the option is elective. In years when the price of oil did not dip below the price for put options, the Hacienda team allowed its options to expire unused. If a put option is unused, the buyer of the option is only out the cost of the option, while the guaranteed sell price is guaranteed, regardless of an asset's actual market price. (For an illustration, see the simple model presented on pp. 17-19.) Put and call options can be attractive hedging tools because their cost is defined from the beginning. As there are no additional or hidden costs or fees beyond the initial guaranteed price, the only money at risk is the initial funds used to purchase the put or call options.

There are three types of put options: American, European, and Asian. American put options are the most expensive; they allow the owner to exercise the option at any point between the purchase and expiration of the option. European options are cheaper; they allow the owner to sell only at the end of the duration of the contract. Asian options tend to be the least expensive. Their strike prices are calculated as an average over a period of time, in contrast to European and American options, where the strike price is calculated at a single specific point in time. For Asian options to be advantageous to the Mexican government, oil prices need to fall over a period of time, rather than just at a specific moment. This works well for an insurance-like hedging program and saves money.

Most put option contracts are denominated in USD or another reserve currency such as JPY, EUR, or GBP. The Mexican government purchases put options in USD and is paid out in USD when it exercises the options. It

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does not hedge currency risk in these transactions. In theory, it faces some exchange rate risk by holding options in USD. In practice, however, each time that the Hacienda team has exercised its put options, USD has strengthened relative to MXN. The three major recent turndowns in oil price have all coincided with a flight to the safety of reserve currencies and the strengthening of USD. Indeed, multiple banks have repeatedly offered currency risk protection to the Hacienda when it purchases put options, but it has consistently judged these protections to be too expensive.

Put options are typically purchased from an investment bank. They are more expensive than other forms of options or futures, because they offer a more robust form of insurance, guaranteeing the option to sell at a fixed price in the future, regardless of what happens in the broader market. Puts are also more expensive initially, because the total cost of a put is paid for upfront. Beyond puts and calls, there are other more complex financial instruments used to hedge oil price risk. The Hacienda does not use these more complex instruments.

History of the Hacienda Hedge

In the 1980s, the Mexican government received only a small portion of its revenue from taxation; it was heavily reliant on oil exports to fund the national budget. In some years, oil exports made up more than one third of government revenue. The national budget contained many entitlements, programs with legally mandated spending that limited the government's ability to change the size of its yearly budget. The combination of being heavily reliant on volatile oil prices and having relatively limited budget maneuverability left the Mexican government looking for a way to reduce exposure to fluctuations in the oil price. As Mexico is also not a member of OPEC (Organization of Petroleum Exporting Countries), it is less able to predict and control future prices of oil, as compared to larger exporters like Saudi Arabia.

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The Mexican government began hedging its oil exposure in 1990, though the annual program was only formalized in 2002. In 1990, the price of oil was rising, as the first Gulf War loomed. The Hacienda, however, worried that the rise would be short-lived, and thus set out to hedge its exposure. There were good reasons to worry, as the government had already been hit in the 1985-1986 downturn in oil prices. And indeed prices did fall rapidly after the conclusion of the first Gulf War. By buying put options in 1990, the government received more total oil revenue than if it had simply sold all its oil on the open market. Despite this success, it would not begin hedging again until 2002 due to the large upfront cost required in hedging and the strength of the oil market for much of the 1990s.

During the 1990s, the Mexican government experienced a major downturn in oil revenue, as world oil prices fell by more than 50 percent from 1996 to 1998. As it had not hedged any of its exposure, public revenues fell precipitously. In response, the government passed legislation to allow for the creation of a larger scale hedging program and granted the Central Bank the flexibility to pursue and structure the necessary deals. Thus, in 2001, the modern Hacienda Hedge was born.

From 2001 to 2008, the Hacienda ran the hedge annually, with the exception of 2003 and 2004. From 2005 onwards, the program expanded dramatically. For the period from 2001 to 2007, the Hacienda received no revenue from the hedging program. Despite the significant outlay required to purchase the puts, it continued and expanded the program into 2008. When the 2008 global financial crisis hit, the government received a windfall of $5B dollars in 2009. As these put options were paid upfront and then settled (or paid out) in December of the following year, the put options purchased in 2008 showed up as a windfall in 2009. After this major success, the Hacienda has hedged every year since.

In sixteen out of the twenty years that the government has run the Hacienda Hedge, it has purchased but not exercised its put options. In the other four years, it has received payouts from the put options. The first

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time the hedge paid off was 2009, when the global financial crisis led to a dramatic decline in oil prices. The hedge paid off again in 2015 and 2016, because of an unexpected global decline in oil demand, combined with an increase in supply from fracking in the United States. These two factors led prices to fall nearly continuously from May 2014 to February 2016. The most recent time the Hacienda Hedge paid off was in 2020, when oil prices fell due to the global slump in demand triggered by the COVID-19 pandemic.

Over the past two decades, the Hacienda team's approach to hedging has evolved. Initially, it purchased put options through two banks: Goldman Sachs and Morgan Stanley. It has since gradually added more banks into the mix as well as at least two oil companies' trading desks, BP and Shell. By spreading the scale of transactions across multiple banks and soliciting multiple bids, the Hacienda team has introduced competition and thus lowered the total cost of the hedging program.

The Hacienda has also adjusted the type of put options over time, moving from solely put options for West Texas Intermediate (WTI) to also including so-called Mayan crude, which Mexico also produces. With WTI options, there is a risk that Mayan prices could fall more sharply, leaving a coverage gap between the two products. Buying contracts in Mayan crude eliminates this risk. By varying the options between WTI and Mayan, the government can find the best price every year for the basket of puts.

The Hacienda Hedge is the world's largest oil hedging program, and the team behind it has continuously adjusted its procedures to maintain secrecy. Among the adjustments it has made over time has been to gradually decrease the amount of publicly available information on the strike price and scale of the hedging program. It has also adjusted the timing of purchases in an effort to avoid frontrunning and prevent other market participants from making trades in anticipation. While this hasn't been completely successful, the Hacienda team's adjustments have helped mitigate some of the risk of frontrunning.

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Evaluating the Hacienda Hedge

With twenty years of experience continuously buying a large, yearly basket of put options, the Hacienda Hedge provides a wealth of evidence to evaluate its impact. We consider both the direct costs and benefits and the broader, secondary impacts that the long-running hedge has generated.

In terms of direct costs and benefits, the Hacienda Hedge is currently strongly cash flow positive. As noted above, the hedge has paid off in four out of twenty years (2009, 2015, 2016, and 2021). The hedge only becomes cash flow positive after a major event (such as the 2008 recession or COVID-19 pandemic). It has tended to revert over time to being cash flow neutral, as more years of premiums without payout occur. The Hacienda has maintained the hedge consistently to stabilize oil export revenue—not as a strategy to generate excess profits. Indeed, it took until 2009 for it to see any payouts from the annual hedge.

While the Mexican government's hedging program is currently cash flow positive, the benefits of the hedge can be seen primarily in the second order effects. Beyond the direct revenues, the strategy has been successful in transferring revenue from periods of high oil prices to periods of low oil prices. A recent paper from the IMF estimates the Hacienda Hedge has lowered the Mexican government's borrowing costs by up to thirty basis points. The hedge ensures that the government is less dependent on the highly volatile price of oil for revenue, thus lowering the risk of default. The hedge further lowers the cost of borrowing by demonstrating an increased fiscal planning capacity, which also leads to a decrease in the perception of the risk of default. In the past twenty years, the Mexican government has spent between 11 and 15 percent of its revenue on interest payments. By lowering default risk, it also lowers the amount paid out in interest payments, increasing spending capacity and lowering the total tax burden.

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The Hacienda Hedge also achieves consumption smoothing. Consumption smoothing is the optimization of consumption between periods of differing income. By smoothing consumption, the government generates higher welfare levels by offering a consistent, predictable level of spending, rather than increasing welfare spending during high oil prices and then cutting back when oil prices decrease. Research shows that citizens strongly prefer consumption smoothing over volatility, with regards to government services. Furthermore, more predictable government spending better facilitates long-term investment in economic development, infrastructure, and other strategic priorities by stabilizing government revenue and thus attracting more private capital investment.

The combined effects of lowered borrowing costs and consumption smoothing are estimated at 0.44 percent permanent increase in consumption. Based on World Bank estimates for total Mexican consumption in 2021, the welfare impact of the Hacienda Hedge was worth up to $4.3 billion USD. This impact is larger than the payout in any given year and estimated to occur every year due to second-order benefits.

The Hacienda Hedge and Other Mexican Fuel Stabilization Strategies

The Mexican government's net oil income is dispersed among the Oil Revenue Stabilization Fund (known as the FEIP), created in 2000; the Federal Treasury, which uses this income for budgeting purposes; and the Mexican Petroleum Fund, a sovereign wealth fund created in 2014 to distribute and manage oil revenues more efficiently for long-term savings.

The FEIP was initially used for short-term stabilization in case of budgetary gaps. It now operates mainly as a supplement to the hedging strategy. Each fiscal year, the government estimates its total oil revenue based on daily production, typically using the same estimate for the average price per barrel as they do for the hedge calculations. A committee of officials from

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the Hacienda decides the allotment from the national budget and the FEIP that will then go towards the hedging strategy. Since at least 2015, the Hacienda has locked in part of its target oil price with the fund. For example, in that year, they locked in a price of $79 for the hedge, with $76.40 guaranteed by options and the rest backed by the fund.

Additionally, from the early 2000s until 2014, as part of the budgetary process, the Mexican government set and subsidized gasoline prices at the consumer level. Following extensive energy reforms passed in 2014, made in an effort to align with market prices, they have gradually reduced subsidies and mostly removed them.

Natural Resource Stabilization Strategies in Latin America

Other Latin American countries have various strategies in place to deal with oil price volatility. Depending on how much oil they export, domestically consume, and require overall, their strategies usually involve some combination of taxes, subsidies, and stabilization funds. Some majority oil-importing governments, including those of **Panama** and **Uruguay**, hedge against import prices.

Over the past decade, many countries in the region have reduced fossil fuel consumption subsidies, but they still utilize them in some capacity, as in response to the COVID-19 pandemic and energy crisis in 2022. Explicit subsidies are meant to keep fuel prices low at the consumer level, but there are a number of issues associated with them, including inefficiency, overconsumption, and high fiscal cost.

Subsidies might be used instead of or together with fuel stabilization funds, which restrict the price of fuel for consumers to a certain range. However, stabilization funds effectively provide a controlled subsidy when oil prices rise, also ending in a high fiscal cost. A fuel stabilization fund is a common

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method of risk management, used in the region by the governments of **Chile**, **Colombia**, and **Peru**. It functions as a pricing mechanism that smooths prices of certain, typically volatile commodities during times of fluctuation. Some countries use a straightforward band approach, as part of which the government establishes a reference price maximum and minimum of oil per barrel, while others have more complex, multi-step formulas.

Such funds are meant to be self-financing, as they generate savings when oil prices are low. But in practice, the funds tend to run up deficits as a result of oil prices remaining high for too long, making it difficult for them to function as long-term solutions to volatility. The experience of each of the aforementioned governments has been that their funds generally operate successfully until they run low on capital during a period of high prices, prompting a transfer of money into the fund from other sources. For example, in **Colombia**, where the government's fund was established in 2007 with money from an existing oil stabilization fund owned by state oil company Ecopetrol, it developed a deficit shortly after, reaching around 1.1 percent of the GDP in 2018 and requiring a government bail-out in 2022, after running up a deficit of 14.1 trillion pesos. Over time, governments end up essentially subsidizing the fund, resulting in unintended, significant, and continuous costs, as opposed to the hedging strategies which involve a fixed total yearly cost.

Beyond Mexico, the governments of several countries that depend on oil imports have tried out hedging strategies in an effort to reduce subsidies and stabilize oil prices. In 2009, the government of **Panama**, where almost half of electricity depends on oil derivatives, developed and successfully executed a hedging strategy that stabilized consumer electricity prices. The **Uruguayan** government, in addition to setting up an Energy Stabilization Fund and diversifying into renewable energy, also tried out hedging in 2008, by entering into a deal with Citibank, and in 2016, by implementing a novel hedging program with the World Bank. In the latter collaboration, the World Bank provided the Ministry of Finance of Uruguay

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with technical expertise and access to markets that they otherwise would not have had. The program proved successful, and the World Bank advised the Uruguayan government in executing a second hedging program in 2019.

The **Ecuadorian** government has been the only other major oil exporter in Latin America to try hedging, but it immediately abandoned the program after losing millions of dollars in the process. The Ecuadorian government relies on oil for about half of their overall export earnings and a third of revenues. In 1993, in the period following the first Gulf War, when oil prices were relatively low, it decided to pursue a hedging strategy, through purchasing put options with Goldman Sachs' J. Aron & Co. They locked in a strike price of $14.88 per barrel for the year and paid out $12 million in fees. The agreement also included the stipulation that the government would pay out more fees if the oil price climbed higher than the strike price. Contrary to their prediction, the actual price for that year averaged out to $15.85 a barrel, and the total fees of the deal ended up totaling almost $20 million. As a result of the money lost, the political opposition at the time alleged corruption, and Ecuador's National Assembly appointed a special committee to investigate those officials at the Central Bank and Monetary Board who were involved in the deal.

Major Latin American oil companies, both state owned and privately held, have frequently employed hedging strategies. Companies including ENAP in **Chile**, Petrobras in **Brazil**, and Ecopetrol in **Colombia** all use a variety of financial instruments to manage risk, including futures, swaps, and options. The goal is to lock in prices to ensure cash flow and protect their profits against drastic drops in oil prices. Oil companies typically deploy a hedging strategy only when necessary, as it may cut into profits depending on the business climate of that year, reevaluating their programs on a yearly basis.

Notably, in **Brazil**, Petrobras has hedged in a manner broadly similar to the Hacienda Hedge. In 2019, Petrobras purchased $320 million in put options

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at $60 a barrel, to hedge against risk of a drop in the price of oil; that same year, the Mexican Central bank hedged at $55 a barrel. The major differences between Petrobras and the Hacienda Hedge are in scale and continuity. Petrobras's hedge was notably smaller than the Hacienda Hedge. This meant it was cheaper, but also offered a smaller amount of insurance against a drop in oil price. The key difference is that Petrobras only hedged in 2018 and 2019, not in 2020, a year where Mexico scored a windfall due to COVID-19's impact on oil prices. By not continuously hedging, Petrobras was uninsured for a major shock to oil prices.

Lessons from the Hacienda Hedge

The success of the Hacienda Hedge, both in providing valuable insurance against downturns in oil prices and in lowering the borrowing cost for the Mexican government, provides multiple lessons for other governments in Latin America. The key lessons are simplicity, efficiency, and continuity.

A major lesson from the success of the Hacienda Hedge is simplicity. This does not mean that the trade does not require planning and expertise. Rather, the trade is simple in that the core aspect of the Hacienda Hedge is the purchase of a large basket of put options, as compared to a more complex strategy, such as puts paired with swaps.

There are many advantages to this simple approach over more complex hedging strategies. First, the cost is fixed and transparent from the outset. Put options can be costly but, unlike futures, there is no risk of forgoing revenue later. In a futures contract, oil is sold at a fixed price at a fixed date in the future. If oil prices increase during that time, the futures contract does not change. In contrast to swaps, there is also no risk of incurring more fees later. In an oil swap, if the price rises, the client is on the hook for the difference between the swap price and market price. Unlike other trading strategies, there are no complex derivatives or other add ons.

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It can be tempting to save money on the initial cost of the put options by modifying the contracts, but this limits the amount of insurance purchased and ultimately undermines the hedging. A more complex hedging strategy might cover a very specific outcome, such as a decline to a particular price or range of prices. The Hacienda Hedge's use of puts instead covers any fall beneath the set price. This means the Mexican Central Bank doesn't need to determine the exact range of fall in a given year; they simply forecast the price and hedge against a general decline. The hedge uses a simple put option that provides a high level of insurance against a decline in oil prices and a transparent cost. The simplicity of the Hacienda Hedge allows for confidence in both the costs and the completeness of the insurance purchased.

A second lesson from the hedge is efficiency. The strategy has worked well because the Hacienda team has constantly sought to improve its efficiency over time, by negotiating put options with multiple banks to lower cost, consistently using cheaper Asian options, and switching from WTI to Mayan crude for the underlying option to maintain insurance levels. As noted above, Asian options are cheaper than European or American options and unlike them, provide insurance over a general decline in price rather than a decline at maturity. This adds efficiency both because the underlying instruments are cheaper and because the desired coverage is insurance for a general downturn—not a means to monetize a forecast of a specific downturn in price. By continuously improving the hedge, the Hacienda team has lowered its annual cost and ensured higher payouts. This constant improvement has helped maintain the political viability of the program, by keeping costs in check and helping to maximize downside protection.

The final lesson from the Hacienda Hedge is the importance of continuity. The strategy is a form of insurance against a decrease in the price of oil. For a highly volatile commodity like oil, it is hard to predict when insurance will be needed. The Mexican government's continuous hedging since 2005 has meant they have been insured during multiple, unexpected

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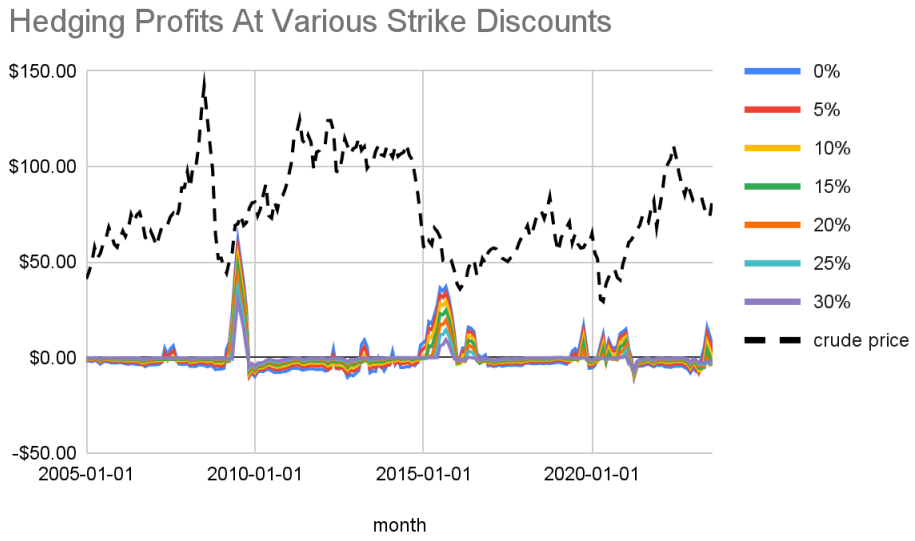
events, such as the 2008 financial crisis and COVID-19 pandemic. By contrast, other oil exporters lost large amounts of revenue due to these shocks. In early years it would have been tempting for the Mexican government to abandon the Hacienda Hedge, as it did not yield revenue until 2009, nearly a decade after the program began. By keeping the hedge continuously, however, the Mexican government ensured that insurance was there when needed. This continuity meant that the Hacienda did not need to perfectly forecast oil prices nor anticipate all shocks to create an insurance program with a net positive cash flow.

A Simple Model to Illustrate the Hedge

Below we illustrate the operation of a hedging program similar to the one implemented by the Mexican government. In order to do so, we simulated the performance of a monthly hedging strategy that purchased insurance for the year ahead in the form of Asian put options at various strike prices starting in 2005 (the first year the Hacienda Hedge was implemented regularly). More methodological details can be found in the technical appendix.



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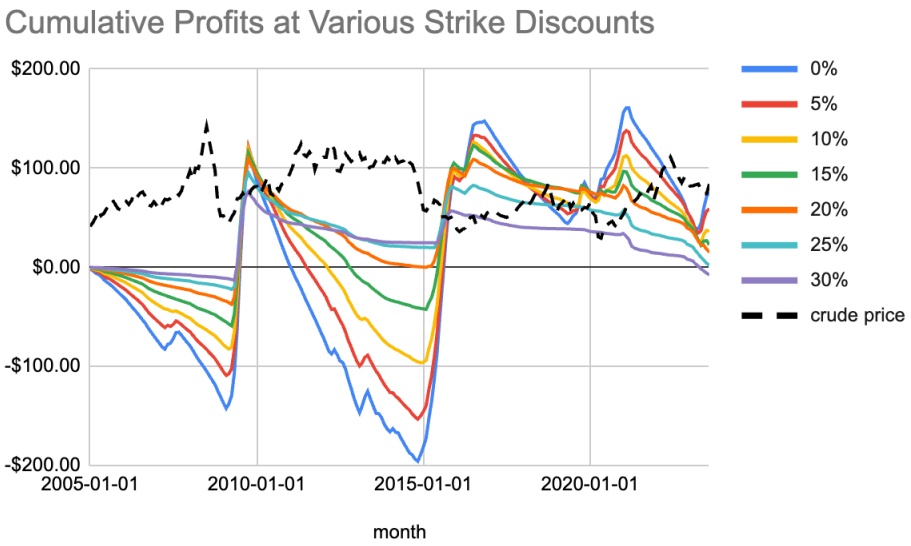
As expected, the strategy ran at a relatively lower cost during benign oil regimes and profited substantially during more volatile periods. This becomes even more apparent when we look at cumulative profits.



The majority of the hedging strategy's simulated profit is realized during three distinct years: 2008, 2014, and 2020–when oil prices plummeted during the Great Financial Crisis, the OPEC strategic overproduction shift, and the COVID-19 pandemic, respectively. This highlights the importance of consistency, especially during higher-price and lower-volatility periods. It is also important to note that the early losses are due to our choice of starting period; had we begun at a different, more volatile period, the strategy arguably would have generated greater profit over its lifetime.

Lastly, cost-savings can be achieved on a per-dollar basis by purchasing insurance at a lower oil price floor. Referring to the technical appendix, one can see there is a "sweet spot" discount around 5 percent of the market price that results in the highest profit rate. This underscores how hedging at price floors too low will mitigate the strategy's upside during volatile

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periods, and hedging too high will incur a performance drag through excessive insurance costs.

Read another way, we can view the strategy's profits as the hypothetical net oil revenue loss avoided during volatile years that accrues to the public's benefit instead. Our simulations show in simplified form how a modest oil hedging strategy can be run relatively inexpensively and mitigate large disruptions to revenue.

This simulation does not imply that any hedging strategy using puts will necessarily be successful. The simulation shows that an actuarially fair crude oil insurance program beginning in 2005 would have likely been profitable at a range of price floors due to crude oil market volatility over the period. This simulation supports further exploration of an oil hedging strategy as a counter-cyclical insurance program.

Conclusion

The Mexican government has continuously hedged its oil risk via the Mexican Central Bank, and to a lesser extent via Pemex, for nearly twenty years. In that time, as the price of oil fluctuated between $19 and $134 dollars per barrel, other oil producers such as the Nigerian and Angolan government have experienced large declines in revenue due to market shocks. The Hacienda Hedge has allowed the Mexican government to avoid the worst of these shocks, while helping to sustain credit ratings and spending.

The Mexican government stands out for both the scale and success of its hedging program. Other governments have hedged but have run into problems with overly complicated strategies and a stop-and-start approach. Simplicity has helped the Hacienda team avoid such pitfalls and keep to its core mission: providing consistent insurance against downturns in price.

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The Hacienda Hedge's core characteristics of simplicity, efficiency, and continuity offer a powerful insight for other oil producers in Latin America, and may hold lessons for exporters of critical minerals and other commodities central to the clean energy transition. By implementing parallel counter-cyclical hedge-based insurance programs, they could mitigate the effects of oil volatility and improve credit risk. The cumulative impact of these improvements makes this a potentially valuable consideration for state actors across the region and world.

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Technical Appendix

We simulated a hypothetical Brent crude oil hedging strategy over two distinct periods: one beginning in January 2005, which roughly aligns with the start of the hedge's regular implementation, and the other beginning in September 1994, the earliest start date possible given available data. Brent crude prices were modeled as a Geometric Brownian Motion, a stochastic process commonly used in quantitative finance to value options. For model inputs, we used: 1. historical Brent crude oil prices as the price of the underlying asset; 2. at-the-the money put option implied volatilities on Brent crude (with adjustments to account for the skew at various strikes); 3. the three-month United States Treasury bill rate as the risk-free rate.

Our modeled strategy used: 1. a one-year hedging period; 2. Asian put options with arithmetic averaging; 3. strike prices at a range of discounts (0-30 percent) relative to the price of Brent crude; 4. payoffs calculated relative to a yearlong average of realized Brent crude prices.

While a closed-form expression exists for valuing Asian options with geometric averaging, one does not exist for valuing the more commonly used contracts with arithmetic averaging. Insead, we used Monte Carlo simulations to measure the performance of the strategy. For each month, we ran 10,000 Monte Carlo simulations of the option value on a per-barrel basis, added antithetics to reduce variance, and averaged these results to arrive at an estimate of the option value for each month. Compared to standard European options, the averaging features of Asian options reduce the volatility of the contract's underlying price, and can allow for substantial cost savings on option premiums.[1]

We include the total premiums, absolute loss avoided, and profit of our simulated strategy over the two periods for illustrative purposes in the

[1] Ilia Bouchouev, "Chapter 11: Volatility Term Structure And Exotic Options", in *Virtual Barrels: Quantitative Trading In the Oil Market* ed. Ilia Bouchouev (Springer, October 2023).

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tables below. From this, we are able to compare the two periods and conclude that net per-dollar profit is highest for the strategy beginning in 2005 when insurance is purchased at a 5 percent market discount. As we can see for the 2005 period, strategy performance is stronger when the hedging period begins when crude oil prices are not near historic lows.

Beginning January 2005

Strike Price Discount Relative to Market Price of Brent Crude	Total Premium Paid	Absolute Loss Averted	Net Profit	Absolute Loss Averted Per USD Paid In Premiums	Profit Per $ Premium
0%	$1,194.79	$1,271.32	$76.54	$1.06	$0.06
5%	$867.58	$926.54	$58.96	$1.07	$0.07
10%	$620.55	$656.82	$36.27	$1.06	$0.06
15%	$438.44	$461.12	$22.68	$1.05	$0.05
20%	$306.62	$321.77	$15.14	$1.05	$0.05
25%	$211.66	$213.51	$1.85	$1.01	$0.01
30%	$144.21	$136.62	-$7.60	$0.95	-$0.05

Beginning September 1994

Strike Price Discount Relative to Market Price of Brent Crude	Total Premium Paid	Absolute Loss Averted	Net Profit	Absolute Loss Averted Per USD Paid In Premiums	Profit Per $ Premium
0%	$1,347.63	$1,382.75	$35.11	$1.03	$0.03
5%	$978.29	$990.46	$12.17	$1.01	$0.01
10%	$699.19	$685.60	-$13.58	$0.98	-$0.02
15%	$493.07	$469.76	-$23.31	$0.95	-$0.05
20%	$343.74	$324.61	-$19.13	$0.94	-$0.06
25%	$236.17	$213.93	-$22.24	$0.91	-$0.09
30%	$160.01	$136.62	-$23.39	$0.85	-$0.15

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