Balancing Volatility and Returns in the Czech National Bank's Foreign Exchange Portfolio: Update on Gold and Bitcoin

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Abstract

This paper discusses the implications of possible changes in the composition of the Czech National Bank's foreign exchange reserves, which are large by international standards and account for about 98% of the CNB's assets and are thus crucial for its earnings. Starting from the allocation as of October 31, 2022, we test how the risk-return characteristics change under the following three hypotheses: (i) increasing the share of equities from about 18% to, for example, 20%, (ii) increasing the amount of gold to, for example, 100 tons (from about 0.5% to 4.5% of the reserves), (iii) reducing the share of euro-denominated assets from 46% to, for example, 40%. The results suggest that if asset prices followed the pattern of the last 20 years, increasing the share of equities to 20% would increase the expected return on the portfolio, while the volatility would increase only slightly. Next, increasing the amount of gold to 100 tons could increase the expected return on the portfolio, while its volatility, measured in Czech koruna, would decrease. Reducing the share of euro-denominated assets, on the other hand, could slightly increase the expected return on the portfolio but could also significantly increase the volatility of the returns measured in Czech koruna, and is therefore not appropriate.

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1. Introduction

After the global financial crisis of 2008, central banks around the world began to use unconventional monetary policy instruments (BIS, 2019). These tools were developed to combat short-term disinflationary pressures or to keep markets running in stressful situations, such as the outbreak of the European sovereign debt crisis and the Covid-19 pandemic.

Unconventional monetary policy led to a significant expansion of central banks' balance sheets. On the asset side, central banks purchased either domestic public/private sector assets (quantitative easing policy) or foreign assets (foreign exchange commitment policy). These purchases were financed by newly created central bank reserves, which appear on the liability side of central bank balance sheets.

A negative side effect of these instruments is that, depending on the accounting principles applied (Archer and Moser-Boehm, 2013; Bell et al., 2023), central banks risk suffering a significant financial loss, which could even cause their net financial position to turn negative. This risk is inherent in the design of unconventional monetary policy instruments, as purchases of long-term financial assets are financed by short-term liabilities. The long-term assets were typically purchased when yields were low (or prices were high) in the case of QE, or when the exchange rate was weak in the case of FX commitments. When monetary policy is subsequently tightened, domestic asset prices usually fall (as yields rise) and the currency in question appreciates, putting pressure on the asset side of the balance sheet. At the same time, central banks have to pay interest on excess reserves when they tighten monetary policy. As a result, many central banks recorded losses in 2022 (the Swiss National Bank, the Fed, the ECB, the Bank of England, the Reserve Bank of Australia, and the Czech National Bank, to name a few) and even reached negative equity (e.g., the Reserve Bank of Australia, the National Bank of Hungary, and the Czech National Bank).

The profitability of central banks, their financial position, and their impact on the ability to achieve price stability have been extensively discussed in the literature and by central bankers (Bell et al., 2023). This discussion is summarized, for example, by Archer and Moser-Boehm (2013) and in the Hildebrand Report (2011) issued by the Central Bank Governance Group of the Bank for International Settlements. These reports conclude that the ability of central banks to achieve their policy objectives does not depend on their profitability or financial strength. Moreover, history shows that central banks can achieve their objectives even with negative equity (e.g., the Central Bank of Chile, the Czech Republic, Israel, and Mexico). However, success depends on the credibility and transparency of the bank, the understanding of the financial markets and the general public of the implications of negative equity, and the fiscal strength of the country's government (Bolt et al., 2023). Empirically, Benecká et al. (2012) show that the link between central bank finances and inflation is very weak and not robust.

In this paper we focus on one part of the Czech National Bank's profitability – the income on its foreign exchange reserves in CZK terms. The CNB's foreign exchange reserves are high by international standards (the level of the reserves is about 50% of nominal GDP; see Table 1) and account for about 98% of the CNB's assets (Table 2). About two thirds of the FX reserves were acquired while the CNB's unconventional foreign exchange rate commitment policy was in place (November 2013–April 2017). Our basic research question is: Can we increase the expected return

on the FX reserves without significantly increasing the risk (volatility) of the portfolio? Volatility was chosen as the measure of risk because it is a basic and universal risk characteristic.

This question has implications for the profitability of the CNB. At the same time, we look at the asset side independently of the liability side (which is driven by monetary policy) and adjust its composition to increase the expected returns over the long term. It is worth noting that our exercise does not have implications for monetary or financial conditions in the economy. This is because monetary policy considerations other than the liquidity of the FX reserves need not be taken into account in this analysis. On the other hand, central banks adjusting their domestic bond portfolio (in the case of reinvestments) need to take into account the maturity profile of the assets they hold, as this affects the shape of the domestic yield curve.

More specifically, we assess how changes in the allocation of the FX reserve portfolio affect its properties in terms of various statistical measures. We consider changes in the composition of the FX reserves along three dimensions: (i) changes in the share of equities in the portfolio, (ii) changes in the weight of EUR in the portfolio, (iii) changes in the share of gold in the portfolio. We use historical data and show how each of the changes in the portfolio affects its historical performance.

The analysis is based on the historical characteristics of asset returns – their means and variances and the correlations between asset classes. It is important to remember that the analysis is based on the assumption that future returns will be distributed like historical returns. The authors are aware that risk characteristics obtained through the statistical processing of historical data are only a representation of the historical behavior of the portfolios, which does not predict how the portfolios or asset classes studied will behave in the future. The computed characteristics are therefore a representation of the past rather than a statement about the future. The time frame in which the analysis is conducted also affects our results. We performed the analysis using the longest available sample (20 years) from the perspective of the CNB's FX reserves model, which is based on historical daily time series of money market interest rates, bond and stock indices, and gold prices. Several robustness checks were performed by considering multiple subsamples (the last 5, 10, 15, and 20 years). A significantly longer time frame than our reference value (20 years) is not relevant for the analysis not only because of the FX reserves model used in this study, but also as the Czech koruna was pegged to a currency basket until 1998 and then the euro was introduced in 1999 (which also changed the currency allocation of the FX reserves).

The analysis suggests that the first two hypotheses improve the risk-return characteristics of the FX reserve portfolio. In particular, increasing the equity allocation to about 20% of the portfolio increases the expected return on the portfolio, while the volatility of the returns shows no marginal increase. Increasing the gold allocation to about 100 tons, which corresponds to about 4.5% of the total reserves, should also increase the expected return on the portfolio, while slightly reducing the volatility of the returns measured in Czech koruna (CZK). A reduction in the euro allocation, on the other hand, could lead to a slight increase in returns, but would also significantly increase the volatility in CZK.

It should be noted that our analysis is based on purely economic grounds, i.e., achieving the highest returns given the level of risk. In practice, broader economic or even geopolitical factors are also taken into account in the composition of the foreign exchange portfolio. For example, the share of euro-denominated assets reflects the Czech Republic's economic links to the euro area and the fact

that the CNB intervenes in the CZK/EUR currency pair. These factors impose constraints on policymakers that go beyond the scope of a portfolio analysis.

The paper is structured as follows. First, we discuss the size and composition of the CNB's FX reserve portfolio and the current approach to its management. We then explain our approach to assessing changes in the portfolio along the three dimensions mentioned above. Finally, we discuss the results and draw policy conclusions.

2. International Reserves of the Czech Republic

The Czech National Bank's foreign exchange commitment policy (2013–2017) caused its international reserves to triple in size. Unlike with quantitative easing policy, the balance sheet does not shrink when the central bank decides to stop reinvesting principal payments from maturing bonds. This is because the central bank has to take an active step to shrink its balance sheet – it has to convert foreign assets into domestic currency. So far, the CNB has not decided to actively reduce its balance sheet significantly.

From a historical perspective, the CNB's FX reserves were relatively high even before 2013. In the 1990s, they were accumulated partly during the period of the fixed exchange rate (until May 1997) in an environment of strong capital inflows and subsequently through foreign exchange interventions against excessive koruna appreciation and the purchase of privatization proceeds from the government.

The level of reserves fluctuated around 20% of GDP until 2013, when the CNB began to use the exchange rate as a monetary policy instrument after reaching the zero lower bound on interest rates (Figure 1). This policy involved the introduction of an exchange rate floor (27 CZK/EUR) to avert the risk of deflation and anchor inflation expectations to the 2% target. Maintaining the commitment required foreign exchange interventions and the accumulation of FX reserves by the CNB. During the period of the FX commitment, the reserves held by the CNB increased by more than 150% in USD terms. By the time the commitment ended (April 2017), they had reached about 70% of nominal GDP, and they subsequently stabilized at about 60% of GDP. In 2022, part of the reserves were used to limit excessive exchange rate volatility in line with the managed float regime. As a result, the level of the reserves decreased to about 50% of GDP.

Figure 1: Foreign Exchange Reserves of the CNB as a Percentage of GDP
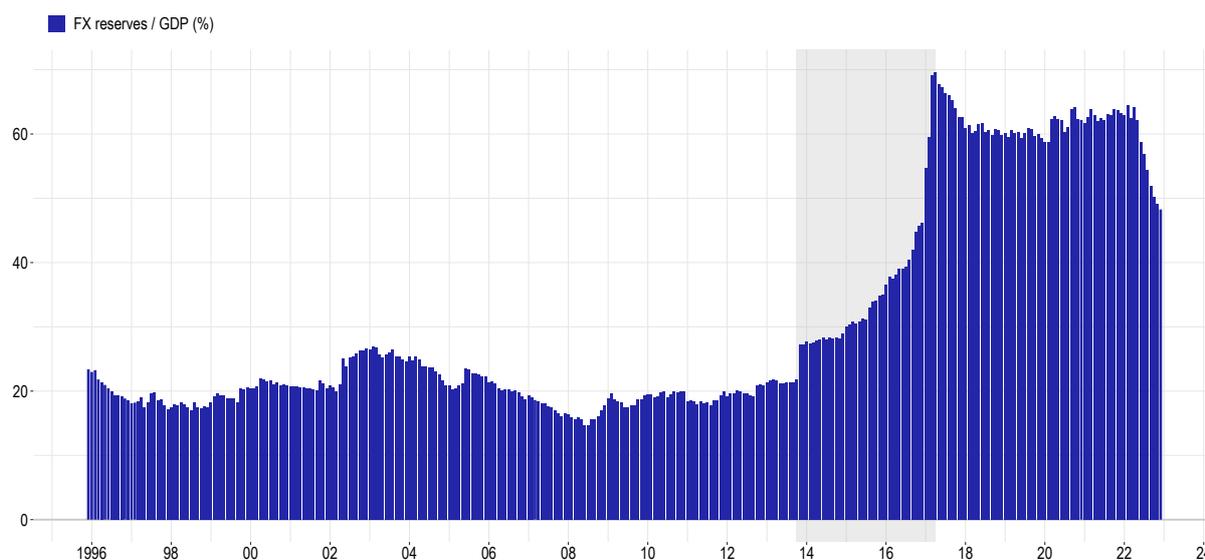
Note: The shaded area indicates the period of the foreign exchange commitment. GDP was interpolated to monthly values using the Chow-Lin Method, and 12m moving sums were subsequently used in the denominator.
Source: CNB ARAD

Measured in terms of GDP, the size of the FX reserves is exceptional by international standards (see Table 1). Among countries with inflation targets, Thailand (49% of GDP) and Israel (44% of GDP) are the countries with the second and third largest reserves, respectively. The country with the largest reserves relative to GDP is Switzerland (136% of GDP).

Table 1: Top 10 Countries with the Highest Ratio of International Reserves to GDP (in %)

	2011		**2016**		**2022**
Hong Kong	114.8	Hong Kong	120.4	Switzerland	136.6
Singapore	85.0	Switzerland	97.6	Hong Kong	135.0
Lithuania	65.0	Saudi Arabia	83.1	Czech Republic	61.5
Iceland	56.2	Singapore	77.8	Saudi Arabia	54.6
Thailand	47.2	Bulgaria	46.7	Thailand	49.0
Switzerland	45.9	Czech Republic	43.7	Bulgaria	48.9
Hungary	34.4	Thailand	40.9	Israel	44.2
Philippines	32.1	Mauritius	40.6	Croatia	41.8
Bulgaria	29.9	Iceland	34.6	Albania	30.8
Israel	28.5	Israel	30.9	North Macedonia	29.8

Source: International Monetary Fund

Mechanics of the CNB's Financial Results

To understand the mechanics of the CNB's profitability, it is worth summarizing its balance sheet (Table 2).

Table 2: Balance Sheet of the Czech National Bank (Dec 31, 2022)

Assets	Liabilities
Foreign exchange reserves (97.8%)	Liabilities to banks operating on domestic market (63.4%)
	Banknotes and coins in circulation (21.9%)
Fixed assets (0.1%)	Other liabilities (1.5%)
Other assets (2.1%)	

Source: Czech National Bank

The CNB's total assets amounted to CZK 3,166 billion (about 50% of nominal GDP) at the end of 2022, of which nearly 98% were FX reserves, including gold. Assets are reported in CZK at the end of the financial year. The other part is fixed assets – the CNB's headquarters in Prague and its branches, as well as other assets. Liabilities consist mainly of commercial banks' deposits with the central bank (roughly 63%) and currency in circulation (approx. 22%). Other liabilities include, for example, deposits of public institutions and liabilities to the International Monetary Fund.

The financial result is mainly determined by the income[†] on assets (FX reserves) and the costs of liabilities (interest rates on commercial banks' deposits with the central bank). Since the income is in international currencies but the accounting is in koruna, there is also a loss or gain on the conversion of FX reserves from euros, dollars, and other currencies into koruna.

The answer to the question of how the CNB can generate a profit in the long run is thus: it must invest its assets, i.e., the FX reserves, in such a way that in the long run it earns more than the potential exchange rate loss due to appreciation of the koruna and the interest costs it pays to commercial banks on their deposits at the central bank. If the expected return on assets is higher than the expected return on liabilities, then even a large loss in a given year (due to high costs of sterilizing bank liquidity or to appreciation of the currency) can be financed by future profits on the FX reserves.

International Reserves Management at the CNB

The vast majority of the CNB's international reserves are actively managed. The remainder are composed of claims on the IMF in the form of special drawing rights (SDRs) and gold held by the

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[†] The CNB applies fair value accounting principles. Income refers to all realized and unrealized foreign exchange gains and losses (dividend and interest income, capital gain income, and income stemming from revaluation of assets due to exchange rate movements).

CNB. The allocation of the actively managed portfolios is the result of the CNB's internal decision-making process, which takes into account the function of the international reserves (support for the CNB's independent monetary policy and a source of foreign exchange liquidity for the CNB's customers) and appropriately considers security, liquidity, and returns. The CNB manages most of its international reserves internally, with the exception of some equity and MBS portfolios, which are managed by external portfolio managers.

The bulk of the international reserves portfolio is invested in debt securities issued by governments of economically advanced countries, selected government-guaranteed bonds, and bonds issued by international institutions with the highest credit ratings (Table 3). Other instruments used in the management of the international reserves include equities, exchange-traded funds (ETFs), repos, covered bonds, deposits with central banks, futures, and interest rate, currency, and equity swaps. All creditor positions vis-à-vis private counterparties are backed by financial collateral.

Table 3: Investment Instruments in the CNB's FX Reserves (Dec 31, 2022)

Type of investment	Share (%)
Bonds	59.6
– government	45.4
– government agencies	7.7
– supranational issuers	2.9
– MBS and covered bonds	3.6
Money market instruments	22.4
Equities	17.5
Other	0.5

Source: Quarterly information on the CNB's international reserves, available at
https://www.cnb.cz/en/financial-markets/foreign-exchange-market/quarterly-information-on-the-cnbs-international-reserves/

The currency composition of the actively managed portfolio reflects the strategic allocation, portfolio returns, changes in the exchange rate of the koruna against reserve currencies, purchases of reserve currencies from clients, and client deposits (Table 4). The euro accounts for the highest share (51.3%). This is because most Czech international trade is conducted with the euro area countries. Currencies with a share of less than 10% (CAD, AUD, GBP, SEK, JPY, CNY) were included for diversification purposes; their weight in the Czech Republic's imports and exports is negligible.

In terms of instruments, the most liquid assets (deposits with central banks and T-bills) are denominated in euros and US dollars. This is due to the fact that foreign exchange interventions are mainly carried out in the CZK/EUR currency pair and the exchange of USD into EUR is easy to perform. Longer-term bonds are held in all currencies except the Japanese yen, which has a long history of low yields. Equities are held in all the major markets of the currencies contained in the FX reserves except SEK and CNY. Finally, the CNB's FX reserve portfolio includes USD-

denominated mortgage-backed securities, giving the portfolio indirect and liquid exposure to the US real estate market.

Table 4: Currency Composition of CNB's FX Reserves (Dec 31, 2022)

	Currency Share (%)	Money Market	Fixed Income	Equities	MBS
EUR	51.3	x	x	x	n.a.
USD	28.6	x	x	x	x
CAD	7.5		x	x	
AUD	4.0		x	x	n.a.
GBP	3.3		x	x	n.a.
CNY	1.8		x		n.a.
JPY	1.6			x	n.a.
SEK	1.1		x		n.a.
SDR	0.4	n.a.	n.a.	n.a.	n.a.
Gold	0.4	n.a.	n.a.	n.a.	n.a.

Note: n.a. = not available
Source: Quarterly information on the CNB's international reserves, available at
https://www.cnb.cz/en/financial-markets/foreign-exchange-market/quarterly-information-on-the-cnbs-international-reserves/

3. Methodology and Data

The objective of this paper is to assess how the characteristics of the FX reserve portfolio change when we adjust it relative to the current portfolio. We consider three dimensions along which we change the reserve portfolio:

1. Increasing the share of equities in the portfolio from about 18% to, for example, 20%.

2. Reducing the share of euro-denominated assets from 46% to, for example, 40%.

3. Increasing the amount of gold in the portfolio to, for example, 100 tons[‡] (from about 0.5% to 4.5% of the reserves).

We rank the portfolios according to two measures – return and risk (captured by volatility). We assess the portfolio characteristics from two perspectives: the reserve currency perspective (the weighted average of the returns on each sub-portfolio in the reserve currencies) and the domestic currency perspective (where the returns are measured in the Czech koruna).

The model is based on historical daily time series of money market interest rates, bond and stock indices, and gold prices. As a benchmark portfolio, we take the CNB's portfolio of FX reserves as composed on October 31, 2022. We obtain the modified portfolios by adjusting the weights (different weights of equities and gold, and different proportions of the euro) in the portfolio. The

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[‡] The amount of gold is expressed in absolute terms, since the representation of gold in FX reserves is traditionally very often expressed in absolute terms (tons).

resulting characteristics (mean, variance) are presented for the annualized moving average returns for the last 5, 10, 15, and 20 years. We use daily data.

Construction of Portfolio Characteristics

1. We use a total of 34 index time series of individual asset classes (interest rates, bonds, MBS and stock indices, and gold) for each reserve currency considered. Summary statistics of the asset returns are presented in Tables A2a and A2b and Figures A1a and A1b in the Appendix.

2. Based on the downloaded data, we build models of the eligible FX reserve sub-portfolios and then calculate their historical daily returns.

3. We set the benchmark portfolio weights (with weights as of October 31, 2022) and alternative portfolio weights (for example, with an equity portion of 20% of the portfolio or a euro portion of 40%). Each time we set the adjusted portfolio weights, we recalculate the remaining weights relative to the initial portfolio.

4. For each set of weights, we construct a series of portfolios and time series of daily historical returns based on a linear combination of the returns on each sub-portfolio.

5. For each of the resulting time series, we compute two time series of 1- and 5-year annualized returns for each day. We know the return for the last year and for the last 5 years.

6. For each of the resulting series (1-year and 5-year annualized returns) we calculate statistics – the minimum, maximum, average, and standard deviation of the returns. We take the data for the last 5, 10, 15, and 20 years.

4. Results

In this section we present and analyze the results of our calculations. We show how the characteristics of portfolio returns change as a function of changes in portfolio allocation. Ultimately, the question is whether the proposed changes to the portfolio can increase the expected returns on, and the stability of, the portfolio.

To approach this question, we use Markowitz's portfolio theory (Markowitz, 1952; Sharpe, 1964; Merton, 1972). We examine the portfolio characteristics from two angles – we look at both the reserve currency returns and the Czech koruna returns. The first approach is appropriate for assessing the success of FX reserves management, as it does not take into account the performance of the Czech koruna. On the other hand, the Czech koruna returns approach is critical to the CNB's financial performance. The data used covers the last 20 years (November 2002–October 2022) and thus includes the global financial crisis of 2008, the outbreak of the Covid-19 pandemic, and also the period of monetary policy normalization in 2022. We also perform a robustness check by presenting the results for several sub-periods (1 year, 5 years, 15 years).

Effects of Portfolio Composition Adjustments on Returns in the Reserve Currencies

Figure 2a summarizes the trade-off between the annual returns (the y-axis) and the assumed volatility of the annual returns (the x-axis). Each point summarizes the portfolio characteristics measured in the reserve currencies[§] and estimated for the whole sample (20 years).

The starting point is the initial portfolio as of October 31, 2022, indicated by the black diamond. It contained about 18% equities and 12 tons of gold, while investment in the euro accounted for about 46%. First, we examine isolated changes in one dimension of the portfolio: changes in the equity share (represented by the red line), changes in the euro share (the green line), and changes in the gold share (the yellow line). Next, we set the equity share to 20% (which is higher than in the initial portfolio) and increase the gold share in the reserves. These combined portfolios are summarized by the blue line.

The figure shows that increasing the proportion of gold in the portfolio provided the best balance between return and risk. This means that for a given increase in the return, the volatility increased the least (as shown by the steepest yellow line). For example, a portfolio with 100 tons of gold had lower volatility than a portfolio with a 20% share of equities (i.e., where the share of equities increases by 2 percentage points), although the return was higher in the first case.

Next, the figure shows important differences between the effects of increasing the share of equities and gold versus reducing the share of the euro. Increasing the equity and gold share of the initial portfolio leads to an increase in both returns and risk, while a reduction in the euro share leads to an increase in returns but also a decrease in risk.

[§] Alternatively, in local currency terms, where "local" means that of each asset.

Figure 2a: **Impact of Changes in the Composition of the FX Reserves on Their Risk Profile (return-volatility) in _Terms of the Return in Reserve Currencies_ (1-year investment horizon, data: _Nov 2002−Oct 2022_)**
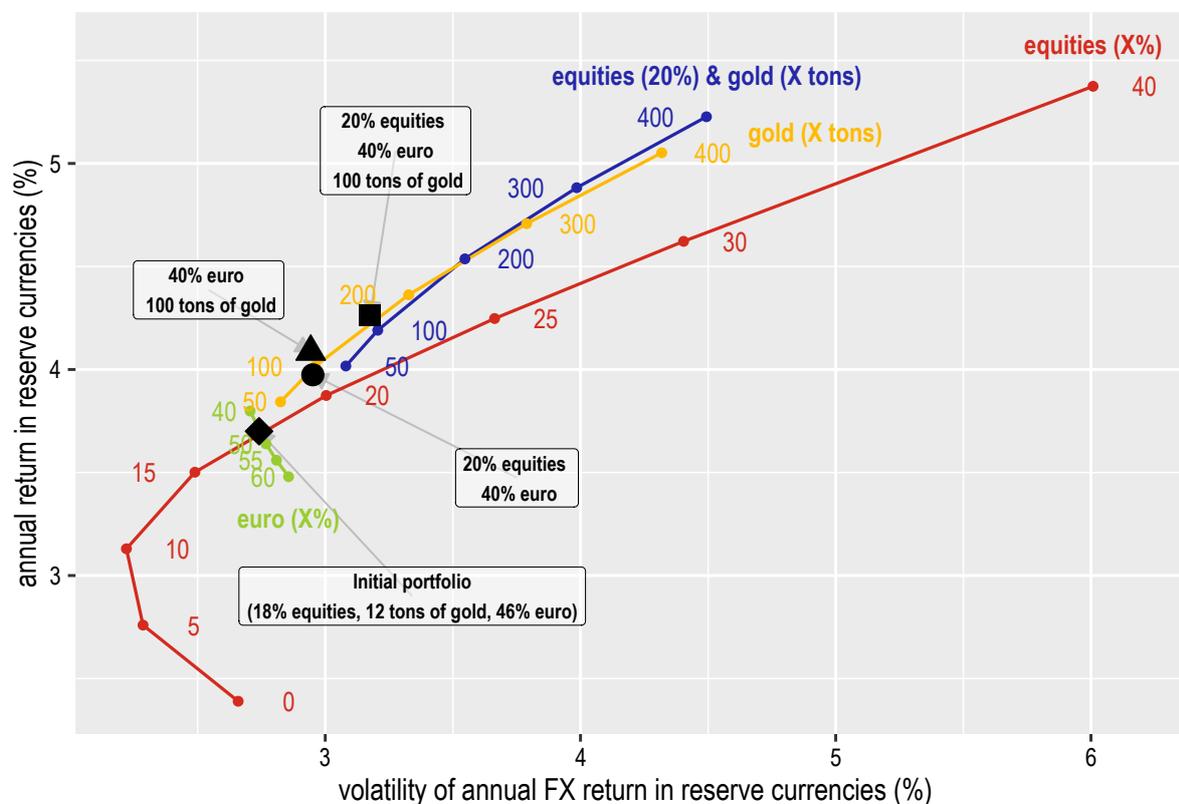
Source: Authors' calculations

At the same time, the figure shows that adjusting the euro component had a smaller impact on risk than adjusting the equity and gold components. For equities (represented by the red line), the portfolio with the lowest variance can be identified – the volatility was lowest at an equity component of 10%. The initial portfolio (approx. 18%) had similar volatility to the portfolio without equities but a much higher return.

The other black symbols in the figure denote the other combinations of the hypotheses tested: 20% equities and 40% euro investment; 100 tons of gold and 40% euro investment; 20% equities, 100 tons of gold and 40% euro investment. Table 5a provides a numerical quantification of the results for the reserve currency returns. The last two columns of the table show the corresponding change (in basis points) in the annual reserve currency returns and the change in volatility compared to the reference portfolio. The initial portfolio, i.e., the composition of the FX reserves as of October 31, 2022 (18% equities, 46% euros, 12 tons of gold), corresponds to an average annual foreign exchange return of 3.70% p.a. and an annual return volatility of 2.74%. The minimum (−8.37% p.a.) and maximum returns (11.72% p.a.) achieved during the period under consideration are also shown. The following lines of the table then show how each of the adjustments in the composition of the reserves (changes in the representation of the euro and equities, increases in gold, and a combination of increases in equities and gold) changes their return characteristics. The rows in gray always correspond to the parameters for the initial composition of the reserves. The bold lines then correspond directly to the hypotheses and combinations of hypotheses examined.

In line with Figure 2a, Table 5a shows that all three portfolio adjustments examined lead to an increase in the annual return in the reserve currencies (the highest increase in return was achieved by increasing the amount of gold to 100 tons). The combination of all three adjustments achieved the largest improvement in the return, increasing it by 56 basis points per year, but also increased the volatility by 43 basis points per year. A similar increase in the returns (55 basis points per year) was achieved by adding 25% equities to the portfolio, but this doubled the volatility increase to 92 basis points per year.

Table 5a: ***Impact of Changes in the Composition of the FX Reserves on Their Risk Profile (return-volatility)*** <u>***in Terms of the Return in Reserve Currencies***</u> ***(1-year investment horizon, data:*** <u>***Nov 2002−Oct 2022***</u>***)***

FX reserves composition		Return (p.a.)			Volatility (p.a.)	Return change (bp)	Volatility change (bp)
		average	min	max			
Composition as of 10/2022*		3.70%	-8.37%	11.72%	2.74%		
Euro	60%	3.48%	-8.20%	12.03%	2.86%	-22	12
	55%	3.56%	-8.26%	11.92%	2.81%	-14	7
	50%	3.64%	-8.32%	11.81%	2.77%	-6	3
	46%	3.70%	-8.37%	11.72%	2.74%		
	40%	**3.80%**	**-8.45%**	**11.58%**	**2.71%**	**10**	**-4**
Equities	0%	2.39%	-7.57%	9.99%	2.66%	-131	-8
	5%	2.76%	-7.79%	7.01%	2.29%	-94	-45
	10%	3.13%	-8.01%	8.24%	2.22%	-57	-52
	15%	3.50%	-8.24%	10.22%	2.49%	-20	-25
	18%	3.70%	-8.37%	11.72%	2.74%		
	20%	**3.87%**	**-8.48%**	**13.04%**	**3.00%**	**17**	**26**
	25%	4.25%	-8.89%	15.93%	3.66%	55	92
	30%	4.62%	-11.81%	18.87%	4.40%	92	166
	40%	5.37%	-17.43%	24.94%	6.01%	167	327
Gold	12 tons	3.70%	-8.37%	11.72%	2.74%		
	50 tons	3.84%	-8.31%	12.08%	2.82%	14	8
	100 tons	**4.02%**	**-8.25%**	**12.53%**	**2.96%**	**32**	**22**
	200 tons	4.36%	-8.12%	14.31%	3.33%	66	59
	300 tons	4.71%	-7.99%	16.46%	3.79%	101	105
	400 tons	5.05%	-7.91%	18.64%	4.32%	135	158
Equities & gold mix	20% & 50 tons	4.02%	-8.43%	13.41%	3.08%	32	34
	20% & 100 tons	**4.19%**	**-8.36%**	**13.86%**	**3.21%**	**49**	**47**
	20% & 200 tons	4.54%	-8.23%	15.21%	3.55%	84	81
	20% & 300 tons	4.88%	-8.10%	17.37%	3.99%	118	124
	20% & 400 tons	5.23%	-8.02%	19.57%	4.49%	153	175
20% equities & 40% euro		**3.97%**	**-8.54%**	**12.91%**	**2.95%**	**27**	**21**
40% euro & 100 tons of gold		**4.09%**	**-8.30%**	**12.43%**	**2.94%**	**39**	**20**
20% equities & 40% euro & 100 tons of gold		**4.26%**	**-8.40%**	**13.76%**	**3.18%**	**56**	**43**

* Composition of the FX reserve portfolio as of October 31, 2022: 18% equities, 46% euro, 12t of gold
Source: Authors' calculations

Effects of Portfolio Composition Adjustment on Returns in the Czech Koruna

Figure 2b and Table 5b reveal that the returns measured in the Czech koruna had higher volatility due to exchange rate risk. The volatility of the returns on the reference portfolio (the CNB's portfolio as of October 31, 2022) measured in the Czech koruna (CZK) was 6.81% per year, approximately 2.5 times higher than that on the returns measured in the reserve currencies.

Looking at the returns from the Czech koruna perspective also led to a different shape of the frontiers. More fundamentally, the location of the reference portfolio corresponded to the minimum variance with respect to the share of equities (the red line). The yellow curve indicates that adding

gold not only increased the returns, but also reduced their volatility up to about 200 tons; the volatility was lowest at about 100 tons of gold, while 200 tons of gold represented a similar risk as the benchmark portfolio. Increasing the amount of gold to about 100 tons led to a 30 basis point increase in the returns in CZK per year and a 3 basis point decrease in volatility.

Interestingly, the Czech koruna and reserve currency risk-return frontiers had similar shapes for changes in the gold and equity shares, but the effect of the euro share was the opposite of that in Figure 2a. Reducing the euro share significantly increased the volatility of the koruna returns, while the return on the reserve portfolio increased only marginally. This phenomenon can be attributed to the higher positive correlation between the euro and the koruna compared with the other reserve currencies.

In more detail, reducing the euro's representation to 40% of the reserves increased the volatility of the koruna returns to a level of volatility corresponding to an equity representation of almost 30%. The same volatility, for example, significantly exceeded the volatility of the returns corresponding to an increase in the amount of gold to 400 tons. However, the increase in returns attained by reducing the euro representation was negligible, comparable to increasing the share of equities to 20%. Figure 2b shows that the best results were achieved when combining increases in the gold and equity shares.

***Figure 2b: Impact of Changes in the Composition of the FX Reserves on Their Risk Profile
(return-volatility) <u>in Terms of the Return in the Czech Koruna</u> (1-year investment
horizon, data: <u>Nov 2002−Oct 2022</u>)***
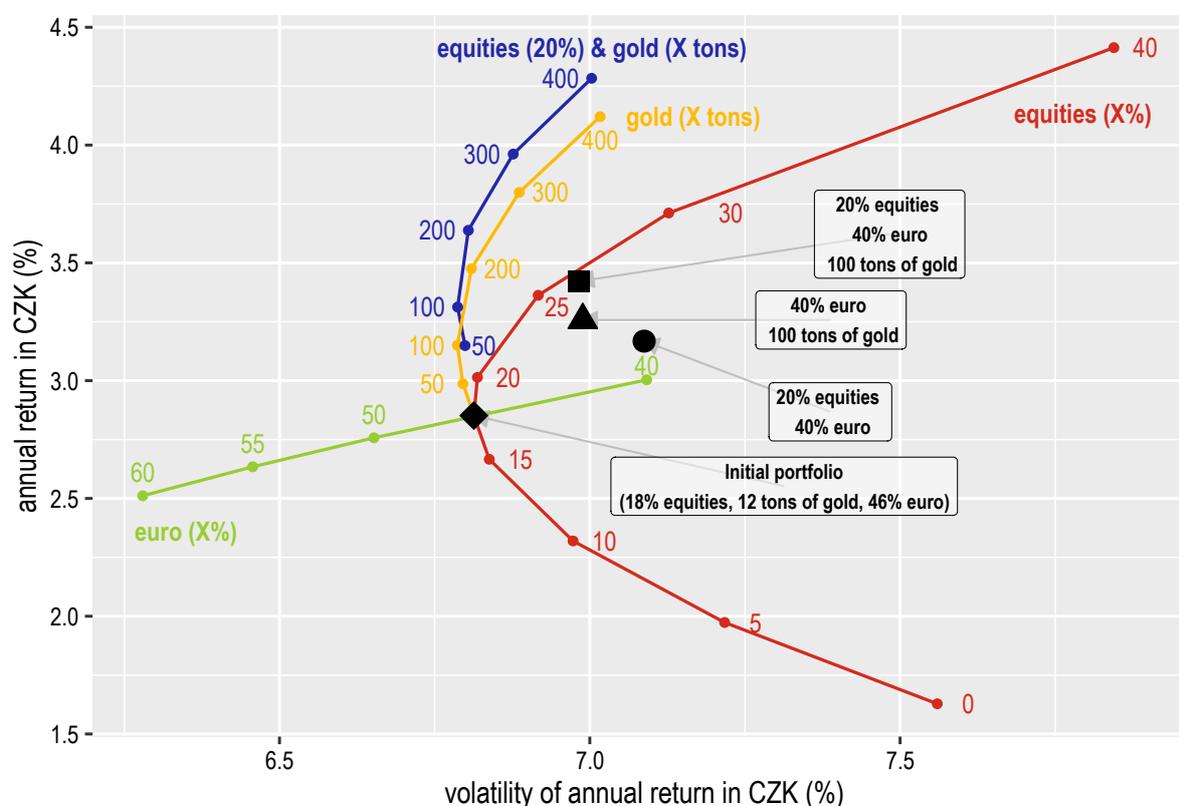
Source: Authors' calculations

Table 5b shows the impact of changes in the composition of the FX reserves on their return
characteristics in the Czech koruna (CZK). A comparison of Tables 5a and 5b confirms the previous
conclusions from Figures 2a and 2b that, of the hypothetical adjustments to the composition of the
reserves and the combinations thereof studied (rows in bold), those that do not involve a reduction
in the euro's representation had a more favorable impact. Their effect was usually even more
favorable than in the case of the reserve currency yield, since, for a similar increase in the yield,
there was a much smaller increase, or even a decrease, in its volatility. This is due to the fact,
discussed above, that reducing the representation of the euro in the reserve portfolio significantly
increased the volatility of the Czech koruna yields.

Similar to Figure 2b, Table 5b shows that all three individual changes to the portfolio led to an
increase in the CZK return, with the highest increase being achieved by increasing the amount of
gold to 100 tons. Regarding the combinations of proposed adjustments, the Czech koruna return
was increased the most by the combination of the three hypotheses. This combination increased the
return by 57 basis points, while increasing the volatility by 17 basis points. However, in order to
reduce the volatility, only the gold and equity shares should be increased, while the euro share
should not be reduced.

Table 5b: ***Impact of Changes in the Composition of the FX Reserves on Their Risk Profile (return-volatility)*** ***in Terms of the Return in the Czech Koruna*** ***(1-year investment horizon, data:*** ***Nov 2002−Oct 2022***)

FX reserves composition		Return (p.a.)			Volatility (p.a.)	Return change (bp)	Volatility change (bp)
		average	min	max			
Composition as of 10/2022*		2.85%	-21.93%	21.11%	6.81%		
Euro	60%	2.51%	-21.55%	19.94%	6.28%	-34	-53
	55%	2.63%	-21.69%	20.30%	6.46%	-22	-36
	50%	2.76%	-21.83%	20.65%	6.65%	-9	-16
	46%	2.85%	-21.93%	21.11%	6.81%	0	0
	40%	**3.00%**	**-22.11%**	**21.89%**	**7.09%**	**15**	**28**
Equities	0%	1.63%	-18.21%	32.87%	7.56%	-122	75
	5%	1.97%	-19.27%	29.49%	7.22%	-88	40
	10%	2.32%	-20.33%	26.15%	6.97%	-53	16
	15%	2.67%	-21.38%	22.85%	6.84%	-19	2
	18%	2.85%	-21.93%	21.11%	6.81%	0	0
	20%	**3.01%**	**-22.42%**	**20.22%**	**6.82%**	**16**	**1**
	25%	3.36%	-23.46%	20.90%	6.92%	51	10
	30%	3.71%	-24.49%	21.85%	7.13%	86	31
	40%	4.41%	-26.68%	23.74%	7.84%	156	103
Gold	12 tons	2.85%	-21.93%	21.11%	6.81%	0	0
	50 tons	2.99%	-21.59%	21.41%	6.80%	13	-2
	100 tons	**3.15%**	**-21.17%**	**21.78%**	**6.79%**	**30**	**-3**
	200 tons	3.48%	-20.32%	22.51%	6.81%	62	0
	300 tons	3.80%	-19.48%	23.20%	6.89%	95	7
	400 tons	4.12%	-18.63%	23.88%	7.02%	127	20
Equities & gold mix	20% & 50 tons	3.15%	-22.08%	20.27%	6.80%	30	-1
	20% & 100 tons	**3.31%**	**-21.66%**	**20.31%**	**6.79%**	**46**	**-3**
	20% & 200 tons	3.64%	-20.82%	20.98%	6.80%	79	-1
	20% & 300 tons	3.96%	-19.98%	21.68%	6.88%	111	6
	20% & 400 tons	4.28%	-19.13%	22.35%	7.00%	143	19
20% equities & 40% euro		**3.17%**	**-22.59%**	**21.56%**	**7.09%**	**32**	**27**
40% euro & 100 tons of gold		**3.26%**	**-21.29%**	**22.34%**	**6.99%**	**41**	**18**
20% equities & 40% euro & 100 tons of gold		**3.42%**	**-21.78%**	**21.22%**	**6.98%**	**57**	**17**

* Composition of the FX reserve portfolio as of October 31, 2022: 18% equities, 46% euro, 12t of gold
Source: Authors' calculations

Robustness Checks: Role of the Time Period

We consider the results for the longest period studied (11/2002–10/2022) to be the most relevant for our long-term analysis. However, several other shorter periods were also examined, as were the return characteristics for annualized 5-year returns. The appendix shows the statistical treatment of the time series of rolling annual and annualized 5-year returns for the last 5, 10, 15, and 20 years – see Tables A1a (in terms of the yield in the reserve currencies) and A1b (in terms of the yield in the Czech koruna).

Examining the results revealed that various time windows have broadly similar characteristics in terms of the risk-return ratio for the proposed changes (changes in the share of the euro and equities and the combination of rising equities and gold). The 5-year returns generally had much lower volatility than the 1-year returns, as a longer investment horizon filters out extremes on both sides of the distribution (gains and losses).

However, there was a notable anomaly: for the November 2012–October 2017 data period and 1-year returns, there was no significant increase in the returns when the amount of gold increases;

instead, only the volatility increased. To better understand this anomaly, we also examined specifically the Nov 2012–Oct 2017 period, which is a subset of the former period and where an even more unfavorable situation occurred – see Figures 3a (reserve currency returns) and 3b (koruna returns). While the mean-variance curves for the various equity and euro holdings had their characteristic shape, especially in Figure 3a, gold showed very different behavior for both the reserve currency and koruna returns. As the amount of gold in the reserves increases, the returns in both reserve currency and koruna terms decreased. On the positive side, for the period Nov 2012–Oct 2022, increasing the amount of gold in the reserves reduced the return, but up to about 100 tons, it reduced the volatility of the return. Above about 100 tons, however, not only did the return decrease, but the volatility also increased. Furthermore, Figure 3b also shows that the curve for equities lost its usual shape and the minimum portfolio volatility is reached when there are no equities in the portfolio.

Figure 3a: FX Reserve Composition Changes and Risk Profile (return-volatility), _Measured in the Reserve Currencies_, over a 1-year Investment Horizon (data: _Nov 2012−Oct 2017_)
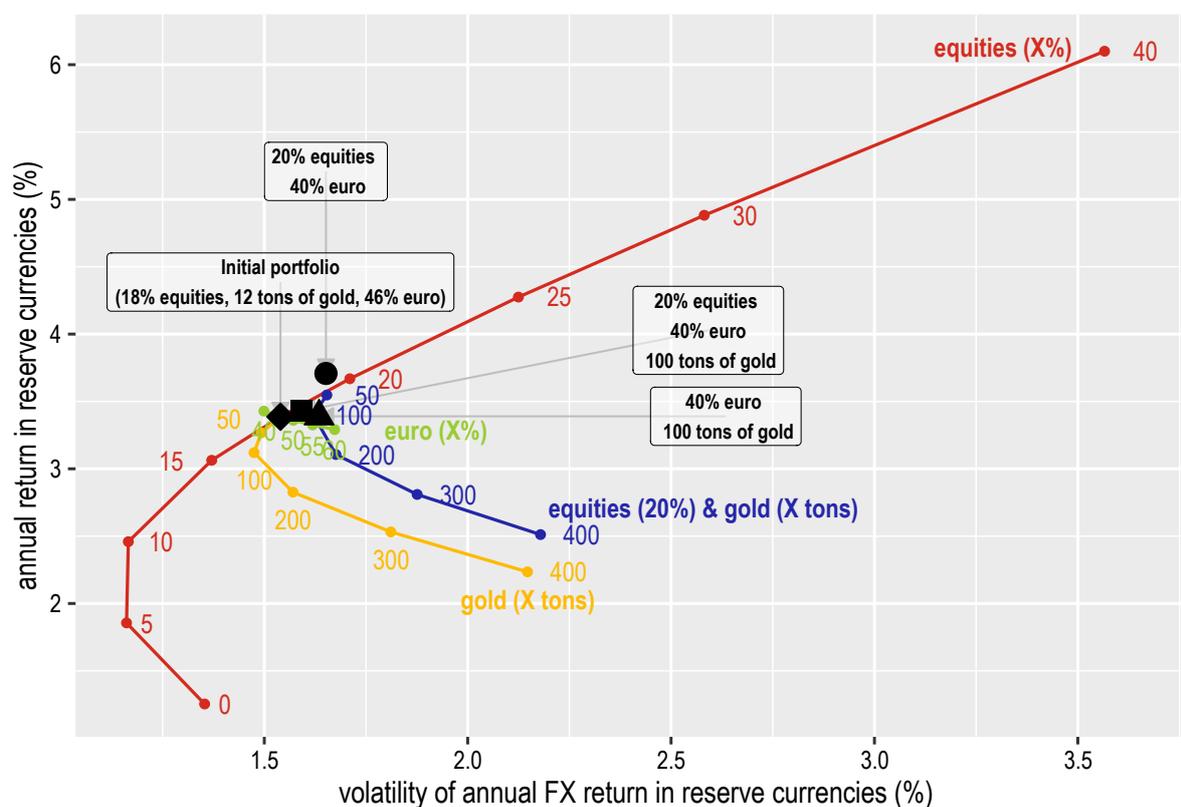
Source: Authors' calculations

Figure 3b: FX Reserve Composition Changes and Risk Profile (return-volatility), <u>Measured in the Czech Koruna</u>, over a 1-year Investment Horizon (data: <u>Nov 2012−Oct 2017</u>)
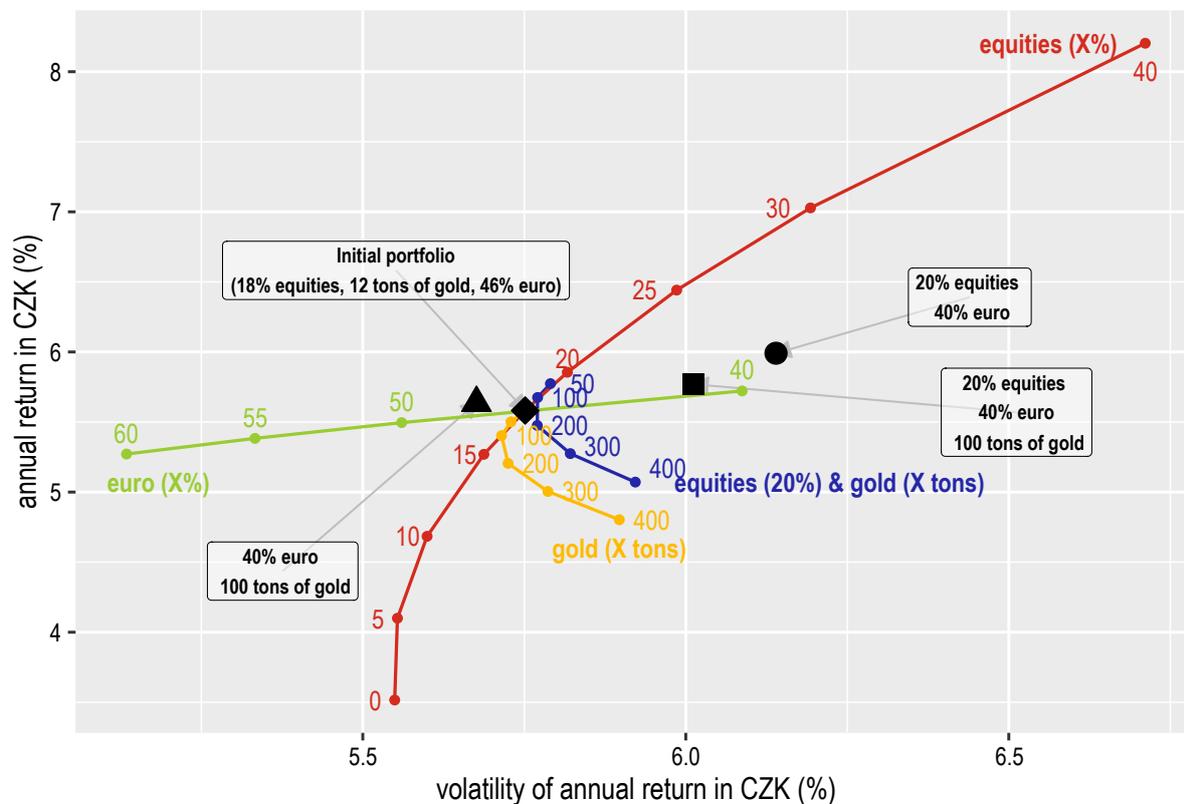
Source: Authors' calculations

The change in the risk-return profile of the gold allocation over the period from November 2012 to October 2017 can be attributed to two factors. First, the value of gold declined in both US dollar and koruna terms during the period. Second, the correlation coefficients between gold and the other asset classes became less stable, as can be seen in Figure 4a. Taking the Czech koruna as the numeraire (as shown in Figure 4b), the correlation coefficients become even more volatile and positive, as they are influenced by fluctuations of the currency.

Figure 4a: *Weekly Rolling Correlations of Returns on Selected Assets, <u>Measured in Local Currencies (USD)</u>; Average Values in Dotted Lines*
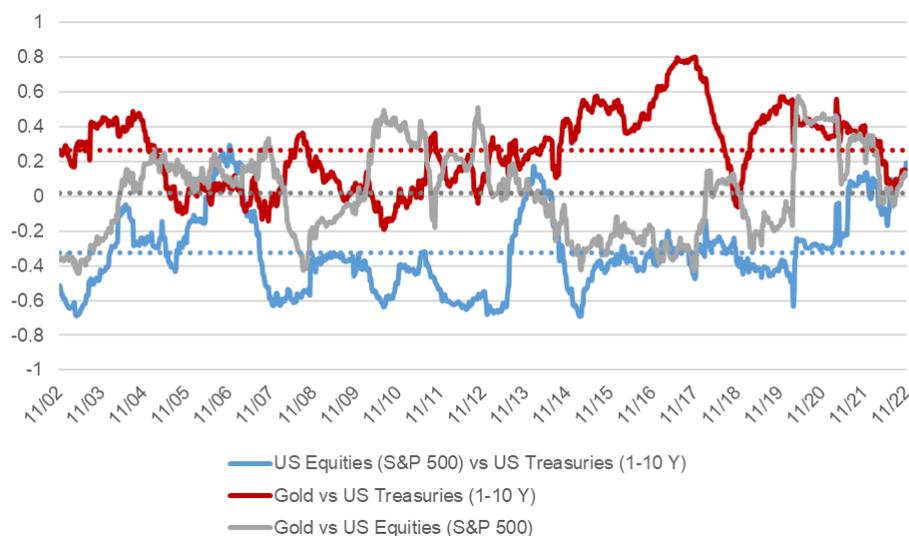
Source: Authors' calculations

Figure 4b: *Weekly Rolling Correlations of Returns on Selected Assets, <u>Measured in the Czech Koruna</u>; Average Values in Dotted Lines*
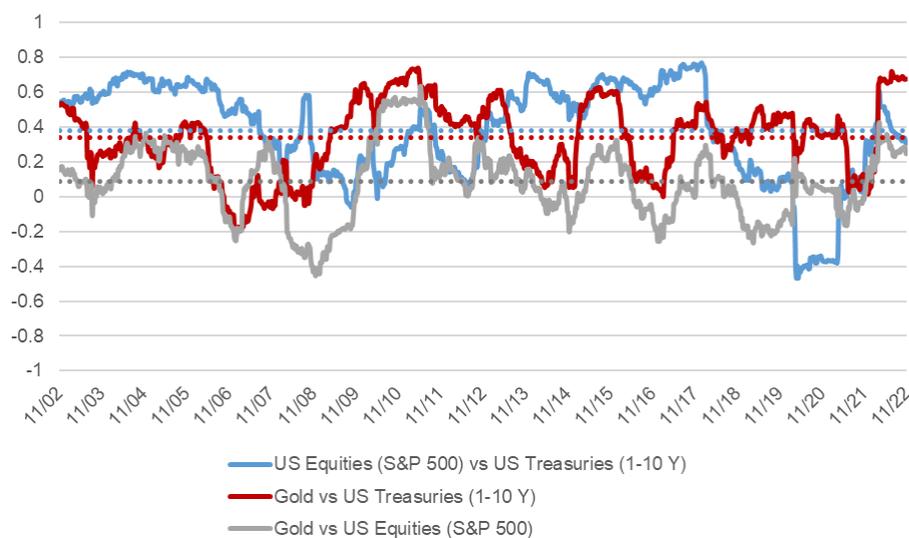
Source: Authors' calculations

The correlation coefficients between gold and local currency-denominated bonds/shares were generally more positive and thus less favorable than those between equities and bonds. On the other hand, the situation reversed when the returns were converted into Czech koruna. Nevertheless, the correlation coefficients were generally higher, as shown in Figure 4b.

5. Other Considerations

The article presents a theoretical concept. In practice, the composition of the foreign exchange portfolio is not only based on portfolio optimization, but also takes into account broader economic

factors. For example, the share of euro-denominated assets reflects the Czech Republic's economic links to the euro area and the fact that the CNB intervenes in the CZK/EUR currency pair.

The paper examines the impact of an increase in two assets (gold and equities) on the risk characteristics of the FX reserves. It is important to note the fundamental difference between gold and equities as an asset. According to the authors' observations, the gold price shows long-term trends that change from time to time, and we cannot predict the breaking points. That is, there are periods when the gold price rises and periods when it falls. When the trend turns, the new trend lasts for a relatively long time. In contrast, equity indices show more erratic trend changes. Moreover, we have to bear in mind that gold has no income component (dividends). As shown in Polášková et al. (2019), the lack of an income component in gold means that extending the investment horizon has a less positive effect on the statistical distribution of the returns for gold than for an equity index.

The round numbers in the hypotheses are not global optima. However, we can see from the effective frontiers that the optimum in terms of the risk-adjusted return always lies in an interval. The tested values are both nice round numbers and close to the optimum, usually at the lower limit of the "optimal" interval.

6. Conclusion

After the global financial crisis of 2008, central banks began to expand their balance sheets in order to ease monetary policy or keep financial markets running in times of stress. This expansion accelerated at the start of the Covid-19 pandemic in 2022. Monetary tightening since 2022 has caused many central banks to incur significant financial losses due to the revaluation of assets acquired during the expansion and to rising interest costs on commercial banks' deposits at the central bank. The literature does not see a close link between the financial strength of central banks and their ability to achieve price stability objectives. However, many consecutive years of financial losses could undermine the credibility of central banks or lead to political pressure on monetary policymakers.

In this paper, we focused on one part of the Czech National Bank's profitability – returns on assets. In particular, we looked at the returns on the FX reserves, as these make up the largest part of the CNB's assets. We examined the portfolio characteristics from two angles – we looked at both reserve currency returns and Czech koruna local currency returns. The first approach is appropriate for assessing the success of FX reserve management, as it does not take into account the performance of the Czech koruna. On the other hand, the Czech koruna returns approach is critical to the CNB's financial performance. Our final question was how to increase the expected return on the reserves without disproportionately increasing – or, even better, while reducing – the volatility of the returns. If the returns on the FX reserves are higher than the cost of liabilities (the cost of sterilizing excess liquidity) in the long run, the CNB can return to profitability. An advantage of the

CNB's balance sheet structure is that the structure of its FX reserves does not directly influence monetary conditions in the Czech economy and thus the monetary policy stance.

We discussed three options for adjusting the CNB's FX reserve portfolio:

1. Increasing the share of equities in the portfolio from the current 18% to, for example, 20%.

2. Reducing the share of the euro in the portfolio from the current 46% to, for example, 40%.

3. Increasing the proportion of gold in the portfolio from the current 12 tons to, for example, 100 tons (which would represent about 4.5% of the reserves)

The figures in the above hypotheses are "rules of thumb" and do not necessarily represent global optima in terms of the risk-adjusted return. In addition, we examined combinations of the three adjustments mentioned above.

The effects of adjusting the composition of the FX reserve portfolio (increasing the share of equities, reducing the share of euro-denominated investments, and increasing the share of gold) on its return characteristics were examined using the CNB's FX reserve model over a time frame of the past 20 years. The starting point was the composition of the FX reserves as of October 31, 2022, which, in terms of the assets studied, comprised about 18% equities, 12 tons of gold and about 46% euro-denominated investments.

We found that increasing the share of equities consistently increased the return on the FX reserves in both the reserve currency and CZK over the long run. Under the hypothesis tested, i.e., increasing the share of equities in the FX reserves to 20%, the increase in the annual return was 17 basis points p.a. in the reserve currency and 16 basis points p.a. in CZK. As far as the volatility of the returns is concerned, an increase of about 26 basis points p.a. and 1 basis point p.a. can be expected in the case of the reserve currency and the koruna, respectively. It is the consistency of the risk-return characteristics that characterizes the adjustment of the equity share in the reserves.

An increase in the share of gold in the FX reserves to about 100 tons (which corresponds to an increase from 0.5% to about 4.5% of the reserves) had a positive impact on the returns in the long run. The increase in the 1-year return amounted to 30 basis points p.a. in the reserve currencies and 32 basis points p.a. in CZK. As for the volatility, it increased by about 20 basis points per year when measured in reserve currency returns and decreased slightly by 3 basis points per year when measured in CZK. However, there were some sub-periods when an increase in the gold component could slightly reduce the returns (notably in 2012–2017). But even in this period, an increase in the gold share to 100 tons (and 200 tons if the equity share was increased to 20%) leads to a slight reduction in the volatility of both the reserve currency and the CZK returns.

Our results may seem to contradict those of Polášková et al. (2019), who showed that the correlation between the returns on gold and other asset classes is positive when measured in reserve currencies, making gold an asset that is not very suitable as an essential component of FX reserves. However, it is important to stress that Czech koruna returns are the ultimate target of the portfolio allocation changes. When the returns are measured in CZK, our results are consistent with research by Zulaica (2020) suggesting that in risk terms gold can serve as a hedge for reserve currency managers whose returns are measured in a non-reserve currency or for portfolios with high interest rate sensitivity.

Zulaica also points out that even portfolios denominated in reserve currencies can benefit from small gold allocations of between 0% and 5%. Our considered allocation of 4.5% falls within this range.

The hypothesis of reducing the euro share to 40% had a positive effect on the annual return: 10 basis points p.a. in the reserve currencies and 15 basis points p.a. in CZK. As for the volatility of the reserve currency returns on the total FX reserves, it decreased by about 4 basis points p.a. Compared to the other adjustments examined, however, it significantly increased the volatility of the koruna returns by 28 basis points p.a., i.e., to a level corresponding, for example, to an equity share in the reserves of about 25–30% or a gold share of more than 400 tons, while the latter adjustment could generate a higher koruna return.

Therefore, if asset prices follow the pattern of the last 20 years, it would be appropriate to increase the share of equities to about 20% of the FX reserve portfolio and to increase the share of gold to up to 100 tons. Conversely, reducing the share of euros might slightly increase the return, but it could also significantly increase the volatility.

To sum up, the paper confirmed that the parameters of the hypotheses improved the statistical characteristics of the returns and risk. The actual optimization is visible in the figures showing the effective frontier.

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Appendix

Table A1a: Impact of Changes in the Composition of the FX Reserves on Their Return Characteristics <u>in Terms of the Yield in Reserve Currencies</u> for Different periods and Investment Horizons of 1 and 5 Years (data: Nov 2002−Oct 2022)

Date period		last 5 years		last 10 years		last 15 years		last 20 years	
Annualized return over		1 Y	5 Y	1 Y	5 Y	1 Y	5 Y	1 Y	5 Y
Composition as of 10/2022*	min	-8.37%	-	-8.37%	0.66%	-8.37%	0.66%	-8.37%	0.66%
- 18% equities	max	9.59%	-	9.59%	3.32%	11.72%	5.57%	11.72%	6.05%
- 12 tons of gold	average	**2.00%**	-	**2.72%**	**2.54%**	**3.14%**	**3.30%**	**3.70%**	**3.68%**
- 46% euro	volatility	3.21%	-	2.58%	0.55%	2.75%	0.91%	2.74%	0.97%
	min	-8.45%	-	-8.45%	0.82%	-8.45%	0.82%	-8.45%	0.82%
	max	9.56%	-	9.56%	3.54%	11.58%	5.65%	11.58%	6.06%
40% euro	average	**2.17%**	-	**2.82%**	**2.69%**	**3.27%**	**3.42%**	**3.80%**	**3.80%**
	volatility	3.27%	-	2.59%	0.54%	2.73%	0.89%	2.71%	0.95%
	return change (bp)	*16*	*-*	*10*	*15*	*13*	*12*	*10*	*11*
	volatility change (bp)	*6*	*-*	*1*	*-1*	*-2*	*-2*	*-4*	*-3*
	min	-8.48%	-	-8.48%	0.81%	-8.48%	0.81%	-8.48%	0.81%
	max	10.93%	-	10.93%	3.61%	13.04%	5.98%	13.04%	6.36%
20% equities	average	**2.23%**	-	**2.98%**	**2.74%**	**3.27%**	**3.49%**	**3.87%**	**3.81%**
	volatility	3.40%	-	2.75%	0.59%	3.02%	0.92%	3.00%	0.96%
	return change (bp)	*23*	*-*	*26*	*20*	*12*	*19*	*17*	*12*
	volatility change (bp)	*19*	*-*	*17*	*4*	*27*	*2*	*26*	*-1*
	min	-8.25%	-	-8.25%	0.93%	-8.25%	0.93%	-8.25%	0.93%
	max	10.31%	-	10.31%	3.76%	12.53%	5.85%	12.53%	6.85%
100 tons of gold	average	**2.30%**	-	**2.73%**	**2.69%**	**3.38%**	**3.37%**	**4.02%**	**3.96%**
	volatility	3.33%	-	2.57%	0.54%	2.94%	0.92%	2.96%	1.17%
	return change (bp)	*30*	*-*	*1*	*15*	*23*	*7*	*32*	*28*
	volatility change (bp)	*12*	*-*	*-1*	*-1*	*20*	*2*	*22*	*20*
	min	-8.36%	-	-8.36%	1.08%	-8.36%	1.08%	-8.36%	1.08%
	max	11.66%	-	11.66%	4.02%	13.86%	6.24%	13.86%	7.16%
20% equities	average	**2.54%**	-	**2.99%**	**2.89%**	**3.50%**	**3.56%**	**4.19%**	**4.09%**
& 100 tons of gold	volatility	3.51%	-	2.73%	0.59%	3.19%	0.93%	3.21%	1.14%
	return change (bp)	*54*	*-*	*26*	*35*	*35*	*26*	*49*	*40*
	volatility change (bp)	*29*	*-*	*15*	*3*	*44*	*2*	*47*	*16*
	min	-8.54%	-	-8.54%	0.98%	-8.54%	0.98%	-8.54%	0.98%
	max	10.89%	-	10.89%	3.81%	12.91%	6.06%	12.91%	6.36%
20% equities	average	**2.41%**	-	**3.08%**	**2.90%**	**3.40%**	**3.61%**	**3.97%**	**3.92%**
& 40% euro	volatility	3.44%	-	2.74%	0.58%	2.98%	0.90%	2.95%	0.93%
	return change (bp)	*40*	*-*	*36*	*35*	*25*	*32*	*27*	*24*
	volatility change (bp)	*23*	*-*	*16*	*3*	*23*	*-1*	*21*	*-4*
	min	-8.30%	-	-8.30%	1.04%	-8.30%	1.04%	-8.30%	1.04%
	max	10.28%	-	10.28%	3.91%	12.43%	5.92%	12.43%	6.85%
40% euro	average	**2.42%**	-	**2.80%**	**2.80%**	**3.47%**	**3.45%**	**4.09%**	**4.05%**
& 100 tons of gold	volatility	3.38%	-	2.59%	0.55%	2.94%	0.91%	2.94%	1.16%
	return change (bp)	*42*	*-*	*8*	*25*	*32*	*16*	*39*	*36*
	volatility change (bp)	*16*	*-*	*1*	*0*	*20*	*1*	*20*	*19*
	min	-8.40%	-	-8.40%	1.21%	-8.40%	1.21%	-8.40%	1.21%
20% equities,	max	11.62%	-	11.62%	4.18%	13.76%	6.29%	13.76%	7.15%
40% euro	average	**2.66%**	-	**3.06%**	**3.00%**	**3.59%**	**3.65%**	**4.26%**	**4.17%**
& 100 tons of gold	volatility	3.54%	-	2.73%	0.59%	3.17%	0.92%	3.18%	1.12%
	return change (bp)	*66*	*-*	*34*	*46*	*45*	*35*	*56*	*49*
	volatility change (bp)	*33*	*-*	*15*	*3*	*43*	*1*	*43*	*15*

* Composition of the FX reserve portfolio as of October 31, 2022
Source: Authors' calculations

Table A1b: Impact of Changes in the Composition of the FX Reserves on Their Return Characteristics _in Terms of the Yield in the Czech Koruna_ for Different Periods and Investment Horizons of 1 and 5 Years (data: _Nov 2002−Oct 2022_)

	Date period	last 5 years		last 10 years		last 15 years		last 20 years	
	Annualized return over	1 Y	5 Y	1 Y	5 Y	1 Y	5 Y	1 Y	5 Y
Composition as of 10/2022*	min	-11.35%	-	-11.35%	-0.27%	-21.93%	-0.27%	-21.93%	-4.13%
- 18% equities	max	10.92%	-	19.53%	4.29%	21.11%	9.13%	21.11%	9.13%
- 12 tons of gold	average	**0.84%**	-	**3.32%**	**1.98%**	**3.31%**	**4.39%**	**2.85%**	**3.09%**
- 46% euro	volatility	4.95%	-	5.88%	1.01%	7.32%	2.57%	6.81%	2.92%
	min	-11.95%	-	-11.95%	-0.17%	-22.11%	-0.17%	-22.11%	-4.29%
	max	11.69%	-	21.13%	4.41%	21.89%	9.46%	21.89%	9.46%
40% euro	average	**1.07%**	-	**3.50%**	**2.15%**	**3.55%**	**4.60%**	**3.00%**	**3.25%**
	volatility	5.21%	-	6.14%	1.01%	7.61%	2.62%	7.09%	3.02%
	return change (bp)	_23_	_-_	_18_	_18_	_23_	_21_	_15_	_16_
	volatility change (bp)	_26_	_-_	_26_	_0_	_29_	_5_	_28_	_10_
	min	-11.20%	-	-11.20%	-0.28%	-22.42%	-0.28%	-22.42%	-3.97%
	max	10.70%	-	19.96%	4.55%	20.22%	9.17%	20.22%	9.17%
20% equities	average	**1.06%**	-	**3.56%**	**2.17%**	**3.43%**	**4.58%**	**3.01%**	**3.21%**
	volatility	4.88%	-	5.90%	1.02%	7.33%	2.57%	6.82%	2.96%
	return change (bp)	_22_	_-_	_25_	_19_	_11_	_19_	_16_	_12_
	volatility change (bp)	_-7_	_-_	_2_	_1_	_1_	_-1_	_1_	_4_
	min	-11.45%	-	-11.45%	-0.03%	-21.17%	-0.03%	-21.17%	-3.58%
	max	12.20%	-	19.67%	4.14%	21.78%	9.36%	21.78%	9.36%
100 tons of gold	average	**1.17%**	-	**3.38%**	**2.16%**	**3.57%**	**4.51%**	**3.15%**	**3.37%**
	volatility	5.15%	-	5.84%	0.88%	7.30%	2.50%	6.79%	2.76%
	return change (bp)	_33_	_-_	_6_	_18_	_26_	_12_	_30_	_28_
	volatility change (bp)	_20_	_-_	_-3_	_-13_	_-2_	_-8_	_-3_	_-16_
	min	-11.29%	-	-11.29%	-0.04%	-21.66%	-0.04%	-21.66%	-3.42%
	max	11.98%	-	20.11%	4.40%	20.31%	9.41%	20.31%	9.41%
20% equities	average	**1.39%**	-	**3.62%**	**2.35%**	**3.68%**	**4.70%**	**3.31%**	**3.48%**
& 100 tons of gold	volatility	5.07%	-	5.85%	0.89%	7.29%	2.49%	6.79%	2.79%
	return change (bp)	_54_	_-_	_31_	_38_	_37_	_31_	_46_	_40_
	volatility change (bp)	_12_	_-_	_-3_	_-12_	_-3_	_-9_	_-3_	_-13_
	min	-11.76%	-	-11.76%	-0.17%	-22.59%	-0.17%	-22.59%	-4.14%
	max	11.49%	-	21.56%	4.67%	21.56%	9.52%	21.56%	9.52%
20% equities	average	**1.30%**	-	**3.75%**	**2.35%**	**3.66%**	**4.79%**	**3.17%**	**3.37%**
& 40% euro	volatility	5.14%	-	6.14%	1.02%	7.61%	2.61%	7.09%	3.06%
	return change (bp)	_45_	_-_	_43_	_37_	_35_	_40_	_32_	_28_
	volatility change (bp)	_18_	_-_	_27_	_1_	_29_	_4_	_27_	_14_
	min	-11.84%	-	-11.84%	0.05%	-21.29%	0.05%	-21.29%	-3.69%
	max	12.75%	-	20.79%	4.22%	22.34%	9.60%	22.34%	9.60%
40% euro	average	**1.33%**	-	**3.51%**	**2.28%**	**3.74%**	**4.66%**	**3.26%**	**3.48%**
& 100 tons of gold	volatility	5.33%	-	6.04%	0.88%	7.51%	2.53%	6.99%	2.83%
	return change (bp)	_49_	_-_	_19_	_31_	_42_	_27_	_41_	_39_
	volatility change (bp)	_38_	_-_	_16_	_-12_	_19_	_-4_	_18_	_-10_
	min	-11.69%	-	-11.69%	0.04%	-21.78%	0.04%	-21.78%	-3.54%
20% equities,	max	12.54%	-	21.22%	4.49%	21.22%	9.66%	21.22%	9.66%
40% euro	average	**1.56%**	-	**3.76%**	**2.48%**	**3.85%**	**4.85%**	**3.42%**	**3.60%**
& 100 tons of gold	volatility	5.25%	-	6.04%	0.89%	7.50%	2.52%	6.98%	2.86%
	return change (bp)	_71_	_-_	_44_	_50_	_54_	_46_	_57_	_51_
	volatility change (bp)	_30_	_-_	_16_	_-12_	_18_	_-5_	_17_	_-6_

* Composition of the FX reserve portfolio as of October 31, 2022
Source: Authors' calculations

Table A2a: ***Summary Statistics for Individual Asset Classes*** *in Terms of the Yield in Reserve* *Currencies* ***for Different Periods and Investment Horizons of 1 and 5 Years (data:*** *Nov 2002−Oct 2022)*

	Date period	last 5 years		last 10 years		last 15 years		last 20 years	
	Annualizet return over	1 Y	5 Y	1 Y	5 Y	1 Y	5 Y	1 Y	5 Y
EUR Fixed Income Liquidity tranche	min	-0.52%	-	-0.52%	-0.46%	-0.52%	-0.46%	-0.52%	-0.46%
	max	-0.28%	-	0.21%	-0.20%	3.21%	0.99%	3.21%	1.98%
	average	**-0.45%**	-	**-0.29%**	**-0.37%**	**0.24%**	**-0.08%**	**0.48%**	**0.52%**
	volatility	0.05%	-	0.20%	0.08%	1.03%	0.35%	1.06%	0.89%
USD Fixed Income Liquidity tranche	min	0.00%	-	0.00%	0.23%	0.00%	0.08%	0.00%	0.08%
	max	2.22%	-	2.22%	1.05%	5.25%	1.05%	5.42%	3.30%
	average	**1.00%**	-	**0.56%**	**0.80%**	**0.73%**	**0.46%**	**1.22%**	**1.15%**
	volatility	0.79%	-	0.70%	0.27%	1.11%	0.38%	1.57%	1.12%
EUR Fixed Income Investment tranche	min	-7.42%	-	-7.42%	-1.76%	-7.42%	-1.76%	-7.42%	-1.76%
	max	1.40%	-	4.13%	0.86%	10.72%	4.57%	10.72%	4.99%
	average	**-0.83%**	-	**0.19%**	**0.08%**	**1.73%**	**1.32%**	**1.94%**	**2.22%**
	volatility	1.72%	-	1.69%	0.60%	2.88%	1.47%	2.70%	1.76%
USD Fixed Income Investment tranche	min	-12.03%	-	-12.03%	-0.25%	-12.03%	-0.25%	-12.03%	-0.25%
	max	12.06%	-	12.06%	3.63%	14.08%	6.08%	14.08%	7.16%
	average	**1.25%**	-	**1.35%**	**1.96%**	**3.15%**	**2.56%**	**3.11%**	**3.59%**
	volatility	5.46%	-	4.14%	0.84%	4.53%	1.17%	4.15%	1.79%
CAD Fixed Income Investment tranche	min	-9.87%	-	-9.87%	-0.77%	-9.87%	-0.77%	-9.87%	-0.77%
	max	7.07%	-	7.07%	2.33%	13.21%	5.51%	13.21%	6.30%
	average	**0.27%**	-	**1.09%**	**1.33%**	**2.67%**	**2.32%**	**3.08%**	**3.36%**
	volatility	4.24%	-	3.45%	0.60%	3.91%	1.23%	3.69%	1.77%
AUD Fixed Income Investment tranche	min	-12.62%	-	-12.62%	-0.08%	-12.62%	-0.08%	-12.62%	-0.08%
	max	11.33%	-	11.81%	5.08%	19.92%	8.49%	19.92%	8.79%
	average	**1.64%**	-	**2.85%**	**3.40%**	**4.63%**	**4.69%**	**4.63%**	**5.25%**
	volatility	5.50%	-	4.58%	1.17%	5.31%	1.75%	4.79%	1.76%
SEK Fixed Income Investment tranche	min	-9.97%	-	-9.97%	-1.68%	-9.97%	-1.68%	-9.97%	-1.68%
	max	4.56%	-	10.65%	3.11%	13.94%	6.07%	13.94%	6.60%
	average	**-0.54%**	-	**1.03%**	**1.18%**	**2.73%**	**2.64%**	**3.05%**	**3.36%**
	volatility	3.10%	-	3.58%	1.26%	4.27%	1.80%	4.15%	1.84%
CNY Fixed Income Investment tranche	min	-2.74%	-	-2.83%	2.92%	-3.52%	1.13%	-3.52%	1.13%
	max	9.16%	-	10.37%	5.22%	17.39%	5.22%	17.39%	5.84%
	average	**4.09%**	-	**3.83%**	**3.89%**	**3.98%**	**3.79%**	**3.91%**	**3.85%**
	volatility	2.34%	-	3.09%	0.61%	3.70%	0.80%	4.05%	0.88%
GBP Fixed Income Investment tranche	min	-15.94%	-	-15.94%	-2.50%	-15.94%	-2.50%	-15.94%	-2.50%
	max	6.83%	-	8.04%	3.14%	16.32%	7.58%	16.32%	8.66%
	average	**-0.24%**	-	**1.14%**	**1.66%**	**3.47%**	**3.00%**	**3.49%**	**4.08%**
	volatility	3.95%	-	3.67%	1.17%	4.77%	1.84%	4.39%	2.23%
MBS Investment tranche	min	-16.46%	-	-16.46%	-1.52%	-16.46%	-1.52%	-16.46%	-1.52%
	max	9.20%	-	9.20%	3.38%	12.18%	6.10%	12.18%	7.18%
	average	**0.90%**	-	**1.51%**	**2.13%**	**3.21%**	**2.81%**	**3.40%**	**3.88%**
	volatility	5.24%	-	3.97%	0.88%	4.14%	1.18%	3.79%	1.82%
Gold Investment tranche	min	-12.31%	-	-29.05%	-6.20%	-29.05%	-7.76%	-29.05%	-7.76%
	max	38.04%	-	38.04%	12.83%	57.50%	17.04%	70.26%	25.56%
	average	**7.38%**	-	**0.90%**	**3.92%**	**7.83%**	**2.74%**	**10.02%**	**8.71%**
	volatility	12.26%	-	13.19%	4.80%	16.93%	5.99%	16.82%	9.72%
EUR equity Investment tranche	min	-28.30%	-	-28.30%	-4.75%	-48.69%	-6.53%	-48.69%	-10.11%
	max	66.89%	-	66.89%	12.93%	66.89%	17.91%	66.89%	18.90%
	average	**7.19%**	-	**10.54%**	**6.70%**	**5.65%**	**7.51%**	**8.87%**	**5.46%**
	volatility	16.70%	-	15.09%	3.35%	19.31%	4.51%	18.65%	6.14%
USD equity Investment tranche	min	-18.51%	-	-18.51%	3.33%	-47.50%	0.36%	-47.50%	-8.20%
	max	77.80%	-	77.80%	19.86%	77.80%	25.05%	77.80%	25.05%
	average	**15.13%**	-	**14.99%**	**13.37%**	**11.06%**	**13.41%**	**11.73%**	**9.51%**
	volatility	15.34%	-	12.32%	2.97%	17.52%	3.89%	16.03%	6.74%
CAD equity Investment tranche	min	-27.99%	-	-27.99%	-2.67%	-42.03%	-2.67%	-42.03%	-2.67%
	max	71.68%	-	71.68%	12.13%	71.68%	16.85%	71.68%	19.96%
	average	**10.16%**	-	**9.44%**	**7.49%**	**7.25%**	**7.04%**	**10.10%**	**6.96%**
	volatility	13.50%	-	11.87%	2.45%	15.80%	3.27%	15.49%	4.19%
AUD equity Investment tranche	min	-23.55%	-	-23.55%	-1.04%	-45.31%	-3.92%	-45.31%	-4.53%
	max	52.49%	-	52.49%	11.90%	59.25%	16.69%	59.25%	22.60%
	average	**10.00%**	-	**10.75%**	**8.43%**	**7.01%**	**8.35%**	**10.62%**	**7.58%**
	volatility	12.07%	-	10.84%	1.99%	15.85%	3.07%	15.95%	4.77%
GBP equity Investment tranche	min	-27.48%	-	-27.48%	-2.71%	-39.86%	-2.71%	-39.86%	-2.71%
	max	38.19%	-	38.19%	9.72%	65.26%	18.18%	65.26%	18.18%
	average	**5.84%**	-	**7.86%**	**5.26%**	**6.40%**	**6.94%**	**8.53%**	**6.24%**
	volatility	11.83%	-	10.98%	1.95%	14.79%	3.17%	14.04%	3.53%
JPY equity Investment tranche	min	-21.61%	-	-26.96%	-1.31%	-55.82%	-10.22%	-55.82%	-12.49%
	max	84.09%	-	84.09%	23.34%	84.09%	23.34%	84.09%	23.34%
	average	**10.30%**	-	**16.06%**	**10.52%**	**7.73%**	**11.57%**	**10.24%**	**6.66%**
	volatility	16.06%	-	20.76%	4.09%	23.43%	5.81%	22.57%	9.31%

Table A2b: Summary Statistics for Individual Asset Classes <u>in Terms of the Yield in the Czech Koruna</u> for Different Periods and Investment Horizons of 1 and 5 Years (data: Nov 2002−Oct 2022)

	Date period	last 5 years		last 10 years		last 15 years		last 20 years	
	Annualizet return over	1 Y	5 Y	1 Y	5 Y	1 Y	5 Y	1 Y	5 Y
EUR Fixed Income Liquidity tranche	min	-8.81%	-	-8.81%	-2.63%	-16.07%	-2.63%	-16.07%	-4.72%
	max	7.91%	-	9.83%	0.45%	20.72%	3.00%	20.72%	3.00%
	average	**-2.12%**	-	**-0.50%**	**-1.26%**	**-0.55%**	**0.10%**	**-0.78%**	**-0.53%**
	volatility	3.53%	-	3.92%	0.69%	4.92%	1.47%	4.72%	1.56%
USD Fixed Income Liquidity tranche	min	-19.71%	-	-19.71%	-2.60%	-26.77%	-2.87%	-26.77%	-9.75%
	max	19.22%	-	31.93%	4.60%	38.73%	8.08%	38.73%	8.08%
	average	**0.76%**	-	**2.82%**	**1.10%**	**2.14%**	**2.69%**	**0.68%**	**0.72%**
	volatility	9.43%	-	9.46%	1.99%	11.63%	2.70%	11.06%	3.83%
EUR Fixed Income Investment tranche	min	-11.57%	-	-11.57%	-2.93%	-15.64%	-2.93%	-15.64%	-3.93%
	max	8.23%	-	11.18%	1.36%	26.22%	6.93%	26.22%	6.93%
	average	**-2.48%**	-	**0.01%**	**-0.82%**	**0.96%**	**1.51%**	**0.68%**	**1.16%**
	volatility	4.37%	-	4.83%	1.05%	6.35%	2.47%	5.96%	2.24%
USD Fixed Income Investment tranche	min	-20.82%	-	-20.82%	-1.47%	-22.28%	-1.47%	-22.28%	-9.08%
	max	26.38%	-	36.59%	5.31%	48.27%	11.46%	48.27%	11.46%
	average	**0.99%**	-	**3.69%**	**2.25%**	**4.64%**	**4.85%**	**2.63%**	**3.16%**
	volatility	10.68%	-	11.08%	1.88%	13.28%	3.38%	12.68%	4.27%
CAD Fixed Income Investment tranche	min	-8.48%	-	-8.48%	-0.52%	-8.48%	-0.52%	-8.48%	-0.52%
	max	8.38%	-	9.92%	1.89%	12.55%	6.00%	12.55%	6.63%
	average	**0.24%**	-	**0.99%**	**1.00%**	**2.71%**	**2.39%**	**3.06%**	**3.26%**
	volatility	4.47%	-	3.91%	0.48%	4.31%	1.66%	4.06%	1.85%
AUD Fixed Income Investment tranche	min	-16.34%	-	-19.42%	-2.60%	-22.27%	-2.60%	-22.27%	-3.26%
	max	15.75%	-	23.99%	3.51%	39.03%	15.80%	39.03%	15.80%
	average	**-1.00%**	-	**0.81%**	**0.53%**	**4.77%**	**4.46%**	**4.48%**	**4.66%**
	volatility	7.22%	-	8.88%	1.33%	11.88%	4.90%	11.16%	4.69%
SEK Fixed Income Investment tranche	min	-21.80%	-	-21.80%	-5.38%	-21.80%	-5.38%	-21.80%	-5.38%
	max	11.76%	-	14.97%	0.22%	25.67%	9.99%	25.67%	9.99%
	average	**-4.10%**	-	**-1.06%**	**-2.19%**	**1.09%**	**2.03%**	**1.05%**	**1.55%**
	volatility	6.63%	-	6.39%	1.15%	8.13%	4.51%	7.55%	4.02%
CNY Fixed Income Investment tranche	min	-14.29%	-	-14.29%	-0.86%	-20.91%	-0.86%	-20.91%	-2.17%
	max	16.42%	-	41.20%	6.40%	60.27%	13.76%	60.27%	13.76%
	average	**4.06%**	-	**5.59%**	**3.19%**	**6.59%**	**6.16%**	**5.91%**	**5.28%**
	volatility	7.10%	-	10.25%	1.84%	14.09%	3.82%	13.47%	3.73%
GBP Fixed Income Investment tranche	min	-23.67%	-	-23.77%	-7.46%	-41.86%	-7.46%	-41.86%	-13.77%
	max	18.69%	-	59.62%	3.74%	65.88%	21.25%	65.88%	21.25%
	average	**-1.24%**	-	**2.97%**	**-1.23%**	**4.53%**	**5.44%**	**2.50%**	**2.47%**
	volatility	9.02%	-	16.66%	2.59%	20.28%	7.54%	18.81%	7.92%
MBS Investment tranche	min	-20.03%	-	-20.03%	-1.76%	-24.67%	-1.76%	-24.67%	-8.78%
	max	20.95%	-	37.79%	5.91%	49.01%	11.78%	49.01%	11.78%
	average	**0.56%**	-	**3.82%**	**2.43%**	**4.69%**	**5.11%**	**2.90%**	**3.45%**
	volatility	9.84%	-	10.80%	2.15%	13.17%	3.43%	12.45%	4.23%
Gold Investment tranche	min	-15.21%	-	-29.29%	-4.32%	-29.29%	-4.32%	-29.29%	-4.32%
	max	51.07%	-	51.07%	10.79%	51.84%	19.29%	57.86%	21.01%
	average	**7.02%**	-	**2.88%**	**4.14%**	**8.49%**	**4.92%**	**8.65%**	**7.93%**
	volatility	15.23%	-	14.53%	3.43%	15.93%	4.85%	15.62%	6.28%
EUR equity Investment tranche	min	-22.31%	-	-22.31%	-4.47%	-52.56%	-7.86%	-52.56%	-11.75%
	max	57.25%	-	57.25%	13.29%	57.25%	17.57%	62.09%	17.57%
	average	**5.05%**	-	**10.25%**	**5.74%**	**4.71%**	**7.72%**	**7.37%**	**4.42%**
	volatility	14.39%	-	15.15%	3.47%	19.18%	5.02%	18.39%	7.06%
USD equity Investment tranche	min	-7.99%	-	-10.41%	3.82%	-44.31%	1.16%	-44.31%	-11.82%
	max	51.78%	-	53.92%	19.31%	53.92%	25.44%	53.92%	25.44%
	average	**13.87%**	-	**17.05%**	**13.67%**	**11.95%**	**15.90%**	**10.58%**	**9.25%**
	volatility	10.94%	-	12.23%	2.48%	18.08%	4.48%	16.77%	10.10%
CAD equity Investment tranche	min	-24.13%	-	-26.87%	-4.81%	-51.65%	-4.81%	-51.65%	-4.81%
	max	68.71%	-	68.71%	12.06%	77.60%	19.70%	77.60%	19.77%
	average	**9.91%**	-	**8.90%**	**5.77%**	**7.43%**	**6.92%**	**9.98%**	**6.06%**
	volatility	14.66%	-	14.29%	2.96%	19.04%	3.78%	18.66%	4.27%
AUD equity Investment tranche	min	-28.35%	-	-28.35%	-6.15%	-58.72%	-6.15%	-58.72%	-6.15%
	max	69.95%	-	69.95%	10.98%	98.77%	24.41%	98.77%	24.41%
	average	**7.19%**	-	**8.54%**	**5.43%**	**7.65%**	**8.06%**	**10.82%**	**6.90%**
	volatility	13.56%	-	13.45%	2.46%	21.76%	4.49%	20.84%	5.02%
GBP equity Investment tranche	min	-28.05%	-	-28.05%	-6.98%	-51.73%	-6.98%	-51.73%	-10.46%
	max	42.18%	-	42.18%	8.13%	56.05%	19.76%	56.05%	19.76%
	average	**4.70%**	-	**7.34%**	**2.97%**	**4.52%**	**6.92%**	**6.38%**	**3.61%**
	volatility	12.04%	-	12.31%	2.74%	17.75%	5.28%	16.57%	6.68%
JPY equity Investment tranche	min	-20.73%	-	-20.73%	0.44%	-45.50%	-2.77%	-45.50%	-10.39%
	max	59.54%	-	60.34%	17.03%	60.34%	18.09%	67.66%	18.09%
	average	**6.21%**	-	**11.64%**	**9.58%**	**6.89%**	**11.15%**	**7.66%**	**6.08%**
	volatility	12.22%	-	14.44%	3.32%	17.34%	3.99%	17.44%	7.98%

Figure A1a: Summary Statistics for Individual Asset Classes <u>in Terms of the Yield in Reserve Currencies</u> for the Last 20 Years and 5 Years
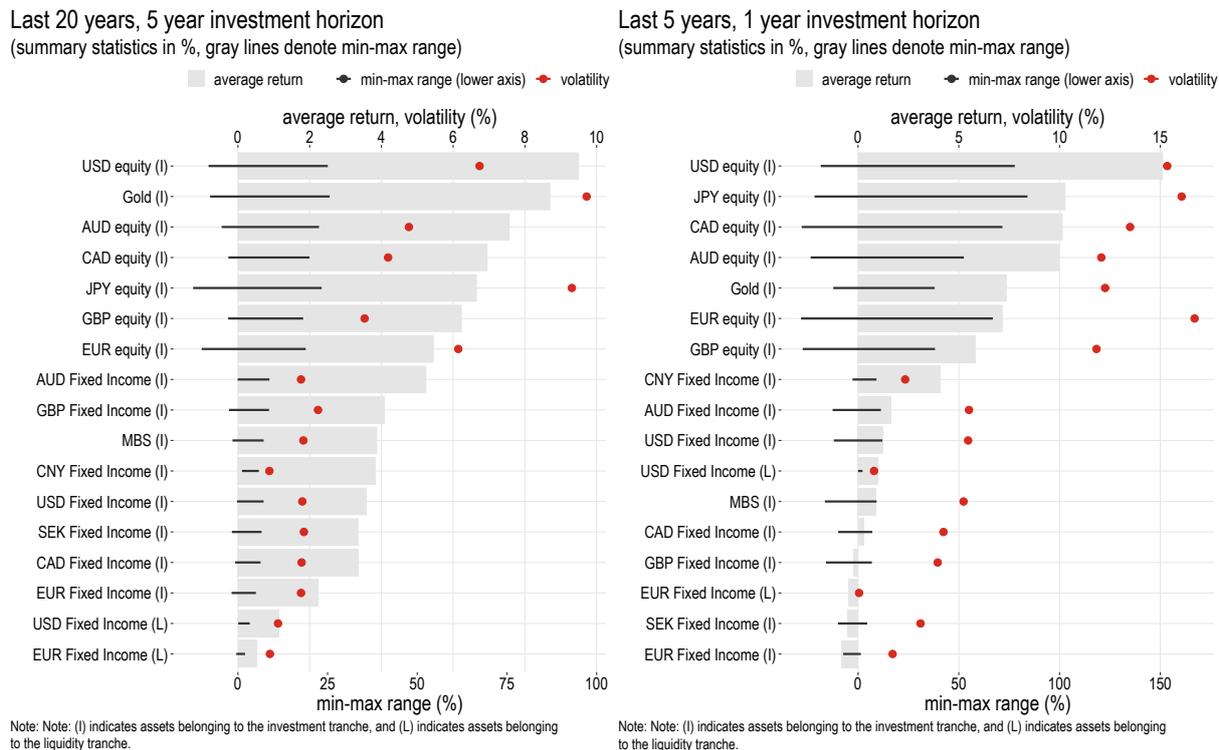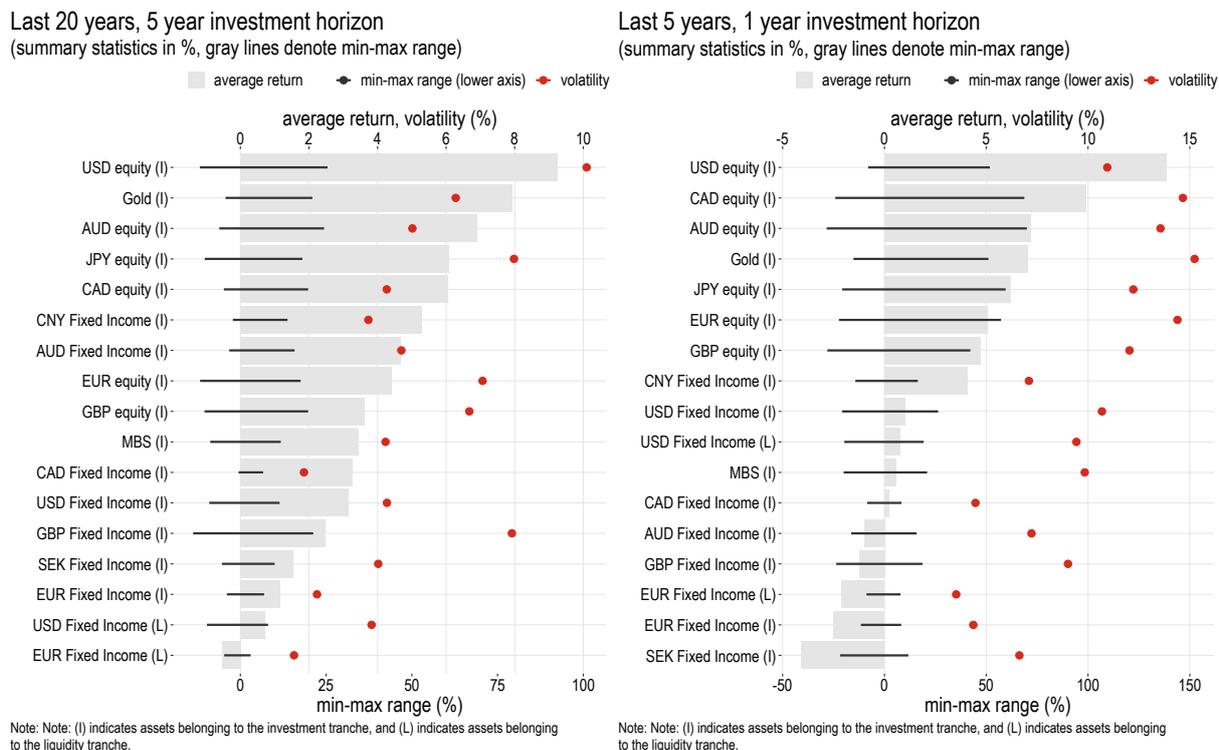

Note: Note: (I) indicates assets belonging to the investment tranche, and (L) indicates assets belonging to the liquidity tranche.

Figure A1b: Summary Statistics for Individual Asset Classes <u>in Terms of Yield in the Czech Koruna</u> for the Last 20 Years and 5 Years

Note: Note: (I) indicates assets belonging to the investment tranche, and (L) indicates assets belonging to the liquidity tranche.

Part II

Balancing Volatility and Returns in the Czech National Bank's Foreign Exchange Portfolio: Update on Gold and Bitcoin

Tomáš Adam, Aleš Michl and Michal Škoda*

Abstract: This paper extends the analysis of the Czech National Bank's foreign exchange reserves portfolio in Adam, Michl, and Škoda (2023) using new data and addresses two developments: the CNB's ongoing gold accumulation toward a 100-ton target (67.2 tons held as of September 2025), and a hypothetical inclusion of bitcoin. The analysis is based on the CNB portfolio as of September 30, 2025, and covers two time horizons (2010–2025 and 2020–2025) in both reserve currencies and Czech koruna. On gold, we find that accumulating toward the 100-ton target represents a modest adjustment that leaves the portfolio's risk-return profile broadly unchanged. On bitcoin, historical data suggest it is a powerful driver of returns achievable with a small allocation; however, bitcoin's short history and unstable financial characteristics limit the reliability of these findings. Given these uncertainties, the CNB's Bank Board decided not to invest its FX reserves in bitcoin at this time, while commissioning a small pilot portfolio of digital assets to build institutional expertise.

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1. Motivation

This paper builds on the Research and Policy Note *Balancing Volatility and Returns in the Czech National Bank's Foreign Exchange Portfolio* (Adam, Michl, Škoda, 2023). It extends that analysis to reflect two distinct developments: the implementation of the CNB's new gold reserves strategy (raising holdings from 9 tons to a target of 100 tons) and a hypothetical examination of the potential inclusion of bitcoin in the portfolio.

First, this paper addresses the strategic expansion of the CNB's gold holdings. Following a 2022 decision by the Bank Board to increase the gold reserves to 100 tons over a five-year time scale, holdings had risen to 71.6 tons by the end of 2025. This accumulation coincided with similar trends at some other central banks (for example, Poland in the region) and a surge in private investor interest, driving gold prices to record highs. Simultaneously, equity markets also saw rapid growth in prices. As this concurrent rally in the two asset classes is historically unusual, this paper re-evaluates the resulting changes in the portfolio's risk-return profile.

Second, at the beginning of 2025, the Bank Board decided to commission an analysis regarding the inclusion of additional asset classes. One such asset is bitcoin. The CNB published a detailed analysis (*Analysis of Investment Options in Other Asset Classes: Part I. Digital Assets*, CNB, 2025) examining the options for purchasing bitcoin for reserves from various perspectives (legal, operational, accounting, and financial).

The impetus for this analysis was the growing institutionalization of the bitcoin market, the emergence of regulated bitcoin ETFs, and the technological maturation of the ecosystem, which create the conditions for bitcoin to be considered alongside other risky financial assets. Furthermore, the analysis was motivated by the overall transition of financial markets toward digitalization and the tokenization of assets, as well as the importance of studying blockchain technologies for future use.

The quantitative analysis was originally applied to the dollar portion of the FX reserves portfolio. This paper examines how the potential inclusion of bitcoin would alter the characteristics of the CNB's actual, total portfolio. We view the inclusion of bitcoin purely through a quantitative lens (risk vs. return), setting aside other risk aspects.

For both gold and bitcoin, the analysis is based on the actual CNB portfolio as of September 30, 2025. We examine return characteristics in reserve currencies and in Czech koruna over both 15-year and 5-year horizons. Before presenting the results of the analysis, we examine the financial characteristics of bitcoin as an asset class, focusing specifically on its volatility and correlation with other assets.

2. Financial Characteristics of Bitcoin

Bitcoin distinguishes itself from traditional asset classes through the magnitude of its returns, its extreme volatility, and the temporal instability of these statistical characteristics. The available time series is relatively short and, even within this limited window, the asset's development has been non-stationary.

1) Returns

Historical returns have been exceptionally high, particularly during the initial years of bitcoin's existence (Figure 1). While its return profile has stabilized somewhat since 2020, bitcoin continues to significantly outperform major equity indices. Rolling returns over three- to five-year horizons remained consistently positive throughout the observed period (2020–2025, Figure 2). In this respect, bitcoin's price development mirrors that of equities, where the probability of incurring a negative return diminishes significantly as the investment horizon extends.

Figure 1: Bitcoin Rolling Returns and Price Evolution
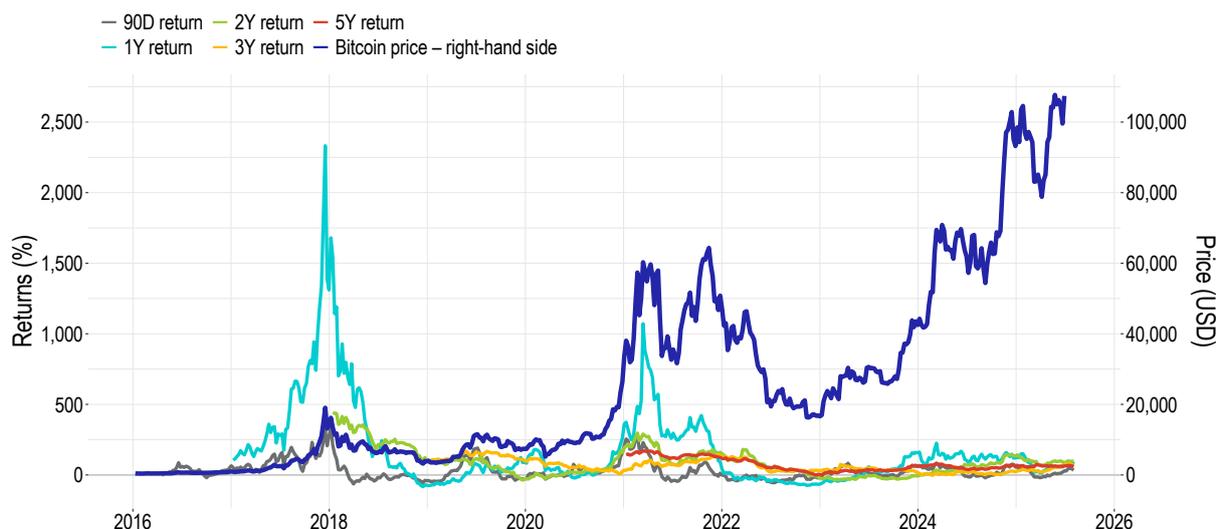
Note: Annualized returns
Source: Bloomberg data; CNB calculations

Figure 2: Bitcoin Rolling Returns Between 2022 and 2025
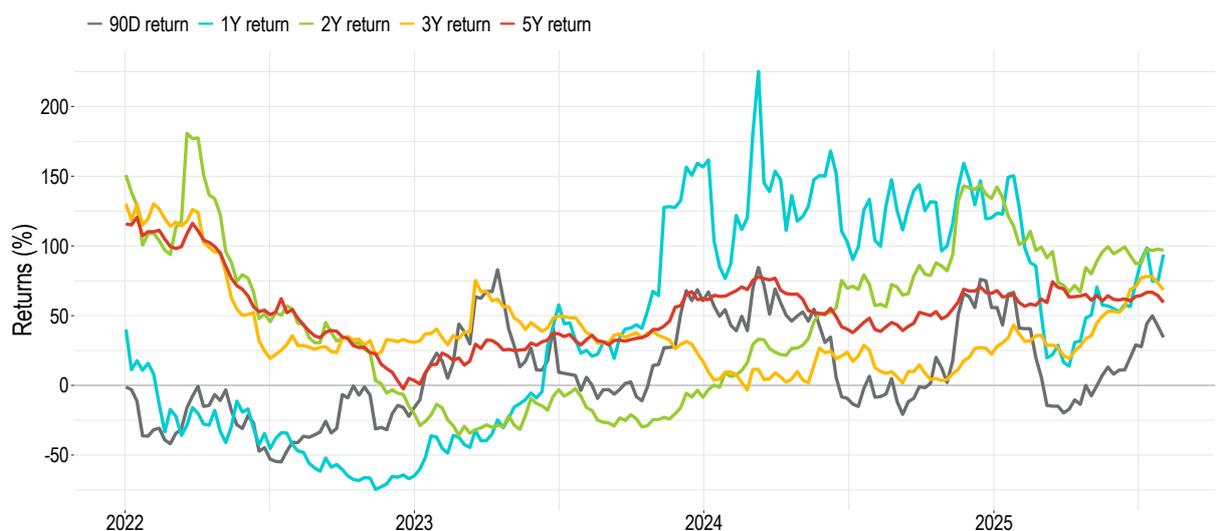
Note: Annualized returns
Source: Bloomberg data; CNB calculations

2) Volatility

Bitcoin's volatility is several times higher than that of equities or gold (Figure 3). The annualized volatility over the five-year period starting in January 2020 was approximately 60%, compared to roughly 20% for equities, 16% for gold, and 6% for bonds. However, the analysis indicates a downward trend, with the volatility in recent years converging toward levels observed in the technology stock sector (Figure 4).

Figure 3: Rolling 90-Day Volatility: Bitcoin and Major Asset Classes
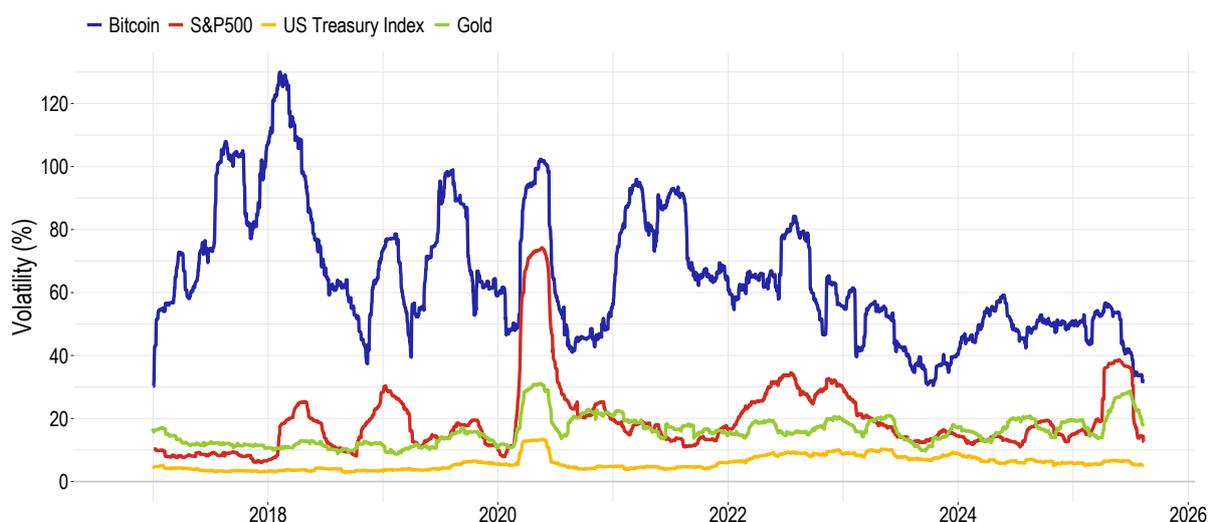
Note: Annualized rolling volatility over a 90-day horizon
Source: Bloomberg data; CNB calculations

Figure 4: Rolling 90-Day Volatility: Bitcoin and Technology Stocks

Note: Annualized rolling volatility over a 90-day horizon

The evolution of bitcoin's volatility over time appears to support the maturation hypothesis—that as an asset gains broader acceptance, it sheds some of its early-stage idiosyncrasy. While 60% volatility is not considered "normal" in traditional finance, the trends suggest that the era of extreme instability (characterized by sharp fluctuations in value) may be receding. The trend illustrated in Figure 4 supports this theory.

Figure 5: Characteristics of 90-Day Bitcoin Volatility
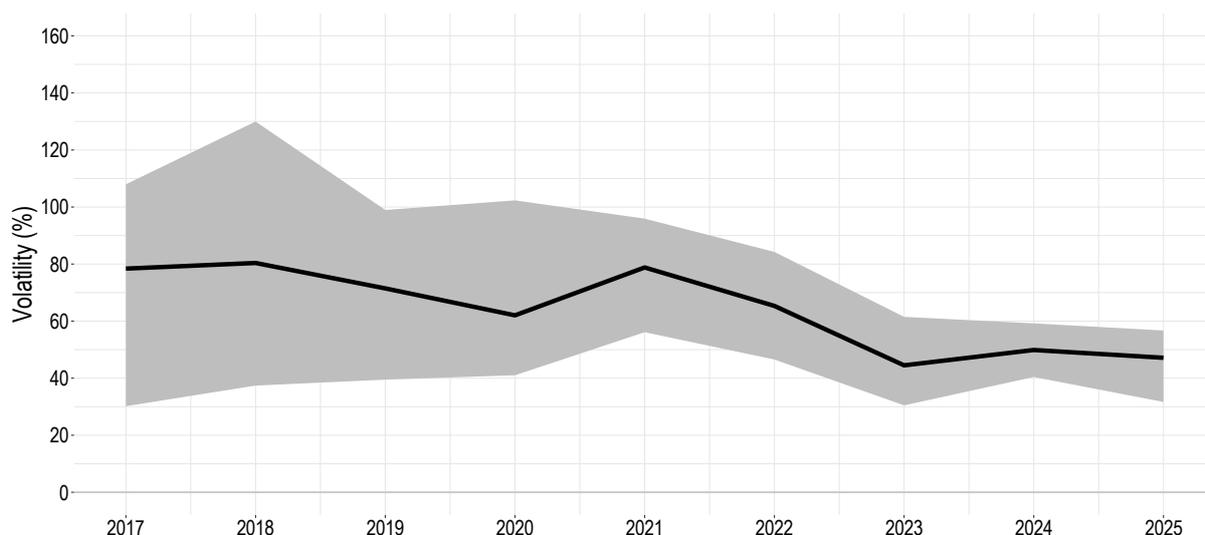
Note: Annualized 90-day rolling volatility, showing the annual mean along with the minimum and maximum values
Source: Bloomberg data; CNB calculations

3) Correlations with Other Assets

Historically, bitcoin's correlation with traditional assets is low (Figure 6), particularly prior to 2020. However, in the post-pandemic era, bitcoin has begun to track the movements of equity markets more closely (with correlations reaching 0.6), while its correlation with bonds often remains negative (Figure 7). This creates a theoretical potential for diversification, though the benefits are less pronounced than in the pre-2020 period.

Figure 6: Correlation Coefficients: Bitcoin Versus Other Assets
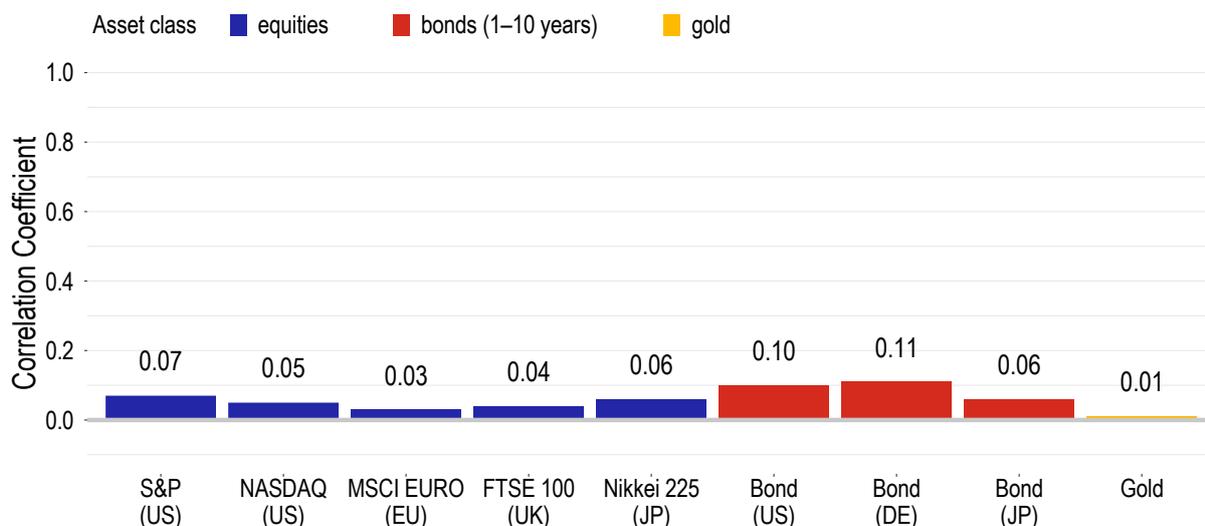
Note: Data for Jan 2011–Sep 2025; in local currencies; monthly frequency
Source: Bloomberg data; CNB calculations

Figure 7: Rolling Correlation Coefficients: Bitcoin vs Bonds, Equities, and Gold
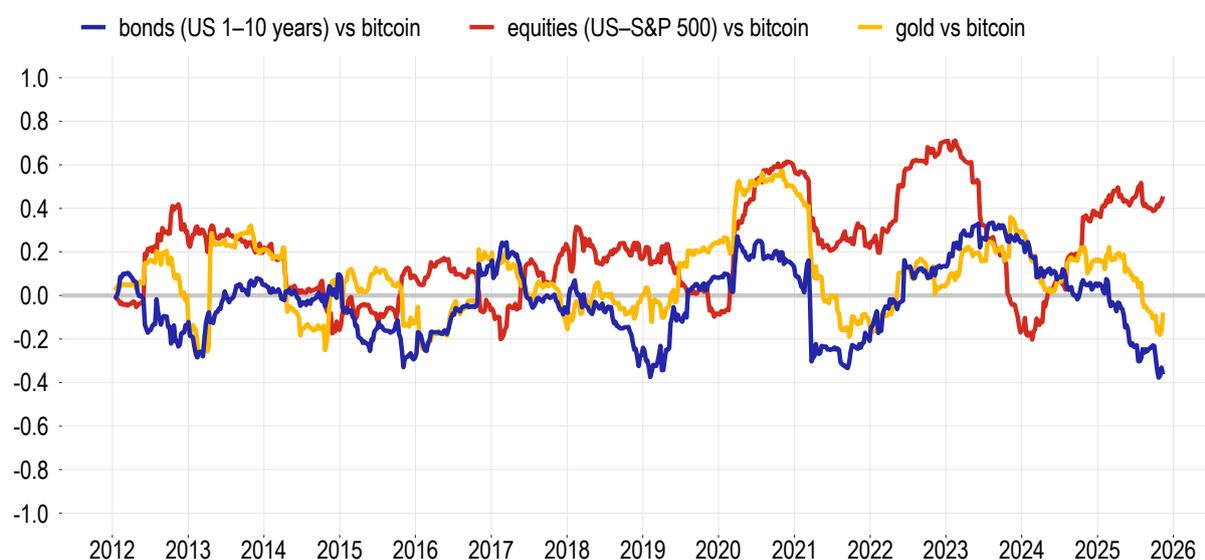
Note: 1Y rolling correlations
Source: Bloomberg data; CNB calculations

Important Caveat: Instability of Characteristics

Temporal instability is a defining feature of bitcoin. Key parameters such as volatility and correlation are subject to extreme variability. Furthermore, the time series is short and heavily skewed by the initial period of explosive growth from near-zero valuation—a trajectory unlikely to be repeated.

These properties imply that historical data serves as a weak guide for forecasting bitcoin's future performance. The risk of "cherry-picking"—selecting a specific time frame that distorts the results—is significantly higher than with traditional assets. The fundamental assumption applied to gold in our previous analysis—that the past holds predictive power for the future—is particularly problematic in the case of bitcoin.

Nevertheless, in the following section, we present an analysis to illustrate how the characteristics of the CNB's foreign exchange reserves portfolio would shift under a hypothetical allocation to bitcoin.

3. Results

We conducted the analysis over two distinct time horizons: the last 5 years (October 2020–September 2025) and the last 15 years (October 2010–September 2025). Consistent with the methodology in Adam, Michl, and Škoda (2023), we analyze the returns over a one-year investment horizon in both reserve currencies and the Czech koruna (CZK).

The baseline portfolio is defined by the reserve composition as of September 30, 2025. This initial portfolio contained 67.2 tons (5.0%) of gold, 25.5% equities, and the remainder in fixed income assets. We modeled allocations of bitcoin ranging from 0% (baseline) to 5% over the observed periods. For gold, its allocations are expressed in tons, reflecting CNB practice and adopted here for consistency, where 400 tons of gold corresponds to approximately 30% of the reserves (i.e., 100 tons are about 7.5%, 200 tons about 15%, and 300 tons about 22.5%).

The curves for equities and gold exhibit characteristics substantially similar to those observed for the reserve composition as of October 2022 (the initial paper results) and the 2002–2022 dataset. This implies that if a policymaker sought to increase the portfolio's expected returns, increasing the equity allocation would introduce less additional volatility than a comparable increase in gold. However, a notable shift is observed: the equity curve is now positioned above the gold curve, with the exception of the scenario involving foreign currency returns over the 2020–2025 period.

For the 2020–2025 dataset, the inclusion of bitcoin impacts the portfolio in distinct ways depending on the currency perspective. In terms of foreign currency returns (Figure 8, (iii)), the addition of bitcoin produces a risk-return profile broadly comparable to an increasing equity allocation. Conversely, in terms of koruna returns (Figure 8, (iv)), it behaves similarly to an accumulation of gold. Crucially, however, bitcoin achieves these effects with a significantly lower allocation magnitude. In the 2020–2025 sample (financed from fixed income), moving from 0% to 4% bitcoin shifts the allocation curve by roughly the same increase in expected return as increasing equities by 15 percentage points (foreign currency case) or raising gold to 400 tons (CZK case), with similar volatility implications. In addition, the rest of the FX reserves could be held in liquid fixed-income assets.

Figure 8: Bitcoin Average Annual Returns and Volatility

(i) Oct 2010-Sep 2025, returns in reserve currencies

(iii) Oct 2020-Sep 2025, returns in reserve currencies

(ii) Oct 2010-Sep 2025, returns in CZK

(iv) Oct 2020-Sep 2025, returns in CZK
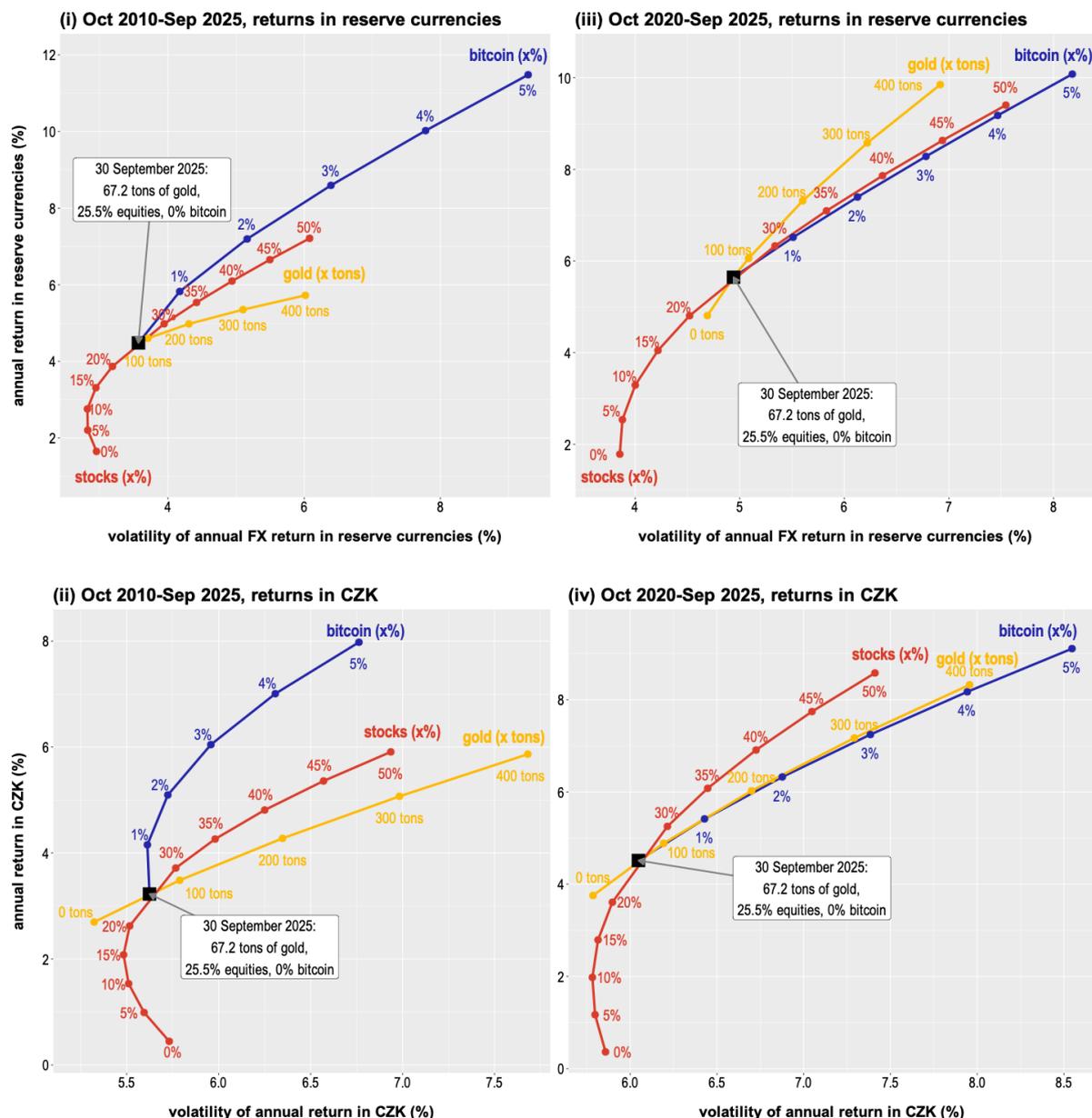
Note: Rolling average returns in %, 1Y investment horizon. Additional allocations are financed by fixed-income assets.

Source: Bloomberg data; CNB calculations

Throughout the period analyzed (2010–2025), in-sample, bitcoin shows a compelling balance between incremental return and volatility (Figure 8, (i) and (ii)). The bitcoin-augmented portfolio allocation curve lies to the left of both equities and gold, indicating that each additional percentage point of expected return is accompanied by comparatively lower incremental volatility. Moreover, for portfolios denominated in CZK, incorporating a 1% allocation to bitcoin slightly reduces the overall portfolio volatility. Consistent with prior findings, even modest allocations to bitcoin can significantly alter the portfolio's risk-return profile. For instance, achieving the same increase in expected return as a 2% allocation to bitcoin would require increasing the equity exposure by more

than 15 percentage points, which would also lead to higher volatility than adding the 2% bitcoin allocation.

However, these results are in-sample and assume that future return distributions resemble the historical sample—an especially fragile assumption for bitcoin. Early-sample dynamics reflected rapid adoption from a low base and large repricing episodes that may not recur as the market matures, implying lower expected returns (and potentially different risk characteristics) going forward. This development might be fueled by increased institutionalization of the market, including the introduction of ETFs and the entry of funds.

4. Conclusion

This paper was motivated by two developments in the management of the Czech National Bank's foreign exchange reserves: the strategic decision to increase gold reserves toward a target of 100 tons, and the commissioning of an analysis on the potential inclusion of bitcoin in the portfolio.

The analysis confirms that the accumulation of gold up to the target of 100 tons is a modest adjustment compared to the current (as of September 2025) 67.2 tons. Based on historical data, this level of allocation maintains the overall risk-return profile of the portfolio while providing a marginal boost to both expected returns and volatility.

In the hypothetical analysis based on historical data, the quantitative results suggest that bitcoin appears to be a powerful driver of portfolio returns and an effective tool to increase the portfolio's expected return. This effect is achieved with a significantly smaller allocation magnitude compared to traditional risk assets such as equities or gold. Specifically, for the entire sample period (October 2010–September 2025), the analysis shows that a 1% allocation to bitcoin could yield a more favorable risk-return profile than a 35% allocation to equities, with the additional benefit of lower overall portfolio volatility compared to the current composition.

For the more recent 2020–2025 period, the impact of bitcoin on the portfolio varies by currency: in terms of foreign currency returns, it behaves similarly to an increased allocation in equities, while in terms of koruna returns, it behaves like an accumulation of gold. In both cases, this effect is achieved with a much smaller allocation magnitude (for example, a 4% allocation to bitcoin compares to a 50% allocation to equities or a 30% allocation to gold).

However, the analysis underscores a critical caveat for bitcoin: its defining characteristic is the temporal instability of its financial properties, including high volatility and shifting correlations. Given the asset's short history and the time-varying behavior of its return characteristics, relying on past performance—particularly the high returns from its explosive initial growth—to forecast its future contribution to the reserve portfolio is significantly more problematic than with traditional assets.

As a result, the CNB's Bank Board decided not to invest its FX reserves in bitcoin yet. At the same time, it decided to create a small, USD 1 million test portfolio of digital assets in Autumn 2025 (Adam, Michl, 2025). The portfolio includes bitcoin, a US dollar-pegged stablecoin, and a tokenized dollar deposit. The goal is to gain practical experience with blockchain-based assets and to learn how to store, manage, and process them safely. Although these assets are not part of the

CNB's official reserves, the experiment will help the bank test how custody, operational procedures, AML compliance, settlement practicalities, accounting, and crisis procedures work in practice.

It will also allow the CNB to compare different types of digital assets. As digital assets become more common in global finance, this project should help the CNB build expertise and prepare for possible future developments. Following a two-to-three-year pilot phase, the CNB will evaluate the experience to define the future course of the project.

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