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Abstract

The paper presents estimates of the macroeconomic effects of the Structural Open Market Operations (SOMO) programme implemented by NBP in 2020 in response to the COVID-19 pandemic shock. In order to assess the *ex-ante* impact of bond purchases by the central bank on the real economy and prices in Poland, (i) the impact of unconventional monetary policy on financing conditions, identified indirectly using the shadow policy rate concept, and (ii) the impact of the SOMO on the exchange rate of the Polish zloty against the euro were estimated. The results of the NECMOD model simulations indicate that the unconventional monetary policy conducted by NBP reduced the extent of the decline in GDP growth and inflation by 0.1 and 0.2 percentage points in 2020 and 0.5 percentage points each in 2021. At the same time, the macroeconomic impact of the SOMO was similar to the effect of the interest rate cuts in the first half of 2020.

Keywords: monetary policy, open market operations, COVID-19.
JEL classification codes: E31, E52, E5

Introduction

In the first half of 2020, the outbreak of the COVID-19 pandemic resulted in an unprecedented collapse of global economic activity. In view of the rapidly increasing number of infections, fast international transmission of the virus, the risk of overburdened health systems, and the relatively high mortality rate, especially among the elderly, most governments decided to introduce a series of sanitary restrictions. These restrictions affected the economy through both the supply and the demand channels. On the supply side, the pandemic and the related restrictions substantially prevented many industries from conducting economic activity and impeded the operation of others, including due to significant disruptions in the supply chain. The rapidly evolving epidemic situation also increased uncertainty surrounding the current and future economic situation. On the demand side, the outbreak of COIVD-19 pandemic adversely affected consumer sentiment and the labour market situation. The simultaneous impact of the demand and supply channels and the high degree of synchronisation of epidemic processes between countries contributed to the biggest fall in global economic activity since the Second World War.

In response to the unprecedented depth of the recession and high uncertainty, the governments of many economies launched anti-crisis programmes. However, these programmes differed significantly from standard stimulation packages, which are usually introduced to boost consumer and investment demand. With the aim of limiting the negative economic consequences of the restrictions imposed and the high uncertainty, the financial aid programmes launched were mainly focused on maintaining the liquidity of enterprises and protecting jobs. Such instruments included loans, tax deferrals or the so-called standstill benefit. In addition to these measures, the anti-crisis assistance was also addressed to employees and households, with fiscal policy instruments varying significantly between economies. Examples include transfers to households and benefits for the unemployed or for persons caring for children (OECD, 2020b).

The fiscal expansion was accompanied by a noticeable easing of monetary policy. The major central banks – like in their response to the previous global economic crisis (in 2008) – decided on a policy of asset purchases (known as quantitative easing) when faced with reaching the lower bound on interest rates; however, the scale of these operations during the pandemic crisis was far greater than previously. Moreover, in response to the outbreak of the pandemic, quantitative easing and other measures that used to be considered as unconventional monetary policy instruments, were applied almost universally in many different economies. According to Fratto et al (2020), as many as 28 central banks in emerging market and advanced economies

(including 8 banks in advanced economies for the first time in history) launched an asset purchase scheme.

In response to the global pandemic shock, Narodowy Bank Polski (NBP) also eased monetary conditions significantly. It lowered interest rates by a total of 140 basis points. In addition, NBP started to purchase government securities and government-guaranteed debt securities on the secondary market under the structural open market operations (SOMO). The purpose of these operations was to change the long-term liquidity structure in the banking sector, ensure the liquidity in the secondary markets for the purchased securities, and strengthen the monetary transmission mechanism. By November 2020, the scale of SOMO asset purchases reached 4.6% of GDP (for 2019) and was close to the average volume of purchases under the quantitative easing performed by central banks worldwide during the pandemic period. However, it should be emphasised that the SOMO programme is not fully identical to previous quantitative easing programmes implemented by central banks following the outbreak of the global financial crisis. The difference between the asset purchase programme of NBP and asset purchase schemes of many other banks is the lack of a fixed and predetermined purchase amount. NBP has no defined quantitative target, e.g. in the form of a monthly purchase of a specified amount of debt securities. Instead, it responds flexibly to changes in market conditions by adjusting the scale of purchases to the current liquidity situation.

The aim of this paper is to present estimates of the macroeconomic effects of the SOMO programme launched by NBP in 2020. In the absence of a sufficiently long time series of historical observations describing NBP's unconventional monetary policy, the macroeconomic effect of the unconventional monetary policy was identified indirectly, using the shadow policy rate (SPR) concept. The SPR is an unobservable short-term interest rate, the level of which is linked to changes in long-term interest rates. Unlike observed money market rates, this rate is not subject to the effective lower band (ELB) and therefore it can be negative.

The study was conducted in two stages. At the first stage, the level of the SPR, corresponding to the volume of asset purchases under the SOMO programme, was estimated. Subsequently, for the period when NBP conducted the structural open market operations, the real money market rate (WIBOR), subject to the effective lower bound (ELB), was replaced in the model by the SPR. At the second stage, this scenario is compared with the counterfactual scenario assuming no asset purchases, where the short-term interest rate in the model is equal to the WIBOR rate throughout the simulation period.

This paper has been structured as follows. The first chapter presents the general characteristics of quantitative easing programmes and potential channels of impact

of these policies on the real economy. It also discusses earlier results of empirical research on the macroeconomic effects of asset purchased by the central bank. The second chapter presents the macroeconomic conditions at the time of launching the structural open market operations programme by NBP. In particular, the cyclical position and the sustainability of the Polish economy in the wake of the pandemic are analysed, the pandemic shock is characterised, and the response of the Polish economy to this shock is described. The third chapter presents the key characteristics of the SOMO programme conducted by NBP. This is followed by an overview of the research method used to evaluate the macroeconomic effects of the SOMO programme. The fifth chapter contains a description and discussion on the effects of asset purchases by the central bank on the Polish economy.

1. Quantitative easing programmes worldwide

Quantitative easing (QE) is a monetary policy tool whereby the central bank purchases a specific class of financial assets denominated in domestic currency, primarily Treasury bonds, in outright operations, for a purpose other than to shape short-term interest rates. By applying quantitative easing, the central bank uses its balance sheet to influence financial asset prices and market conditions. For this reason, quantitative easing is also termed "balance sheet policy", as opposed to interest rate policy (Borio and Disyatat, 2009; Borio and Zabai, 2016). Over the past decade or so, the use of this tool has become increasingly common, initially in advanced economies and, following the outbreak of the COVID-19 pandemic, also in many emerging economies. Consequently, quantitative easing is currently often seen as an important tool of monetary easing.

The forerunner of quantitative easing was the Bank of Japan, which conducted the asset purchases to overcome the problem of persistent deflation in the Japanese economy. The Bank of Japan started its quantitative easing programme as early as 2001 after 10 years of relatively low economic growth and subdued, often negative, inflation rate, and having exhausted the possibilities for conventional monetary policy easing since the central bank interest rate at the time was 0%. The programme continued for the next five years. Within its framework, mainly short-term securities were purchased, i.e. money bills and Treasury bills, which, by increasing the monetary base, was expected to contribute to inflation growth. The scale of the purchases was moderate compared to subsequent programmes and amounted to about 3% of GDP annually.

During the global financial crisis from 2008 to 2010, asset purchases were carried out by the Fed, the Bank of England, and the Bank of Japan, with the aim of making financial markets more efficient and fostering lending. The objectives and design of the these quantitative easing programmes differed from the precursor actions of the Bank of Japan. The aim of the crisis quantitative easing programmes was to increase liquidity in financial markets "frozen" during the crisis and to improve the situation in private credit markets, especially in the mortgage market. The purchases focused primarily on longer-maturity securities – mortgage-backed securities (MBS) in the United States and Treasury bonds in the United Kingdom and in Japan. Upon announcement of the programmes, the Fed and the Bank of England informed about the planned total scale of purchases and their approximate duration (close-ended programme), although subsequently the scale was often increased and

the duration extended. Ultimately, the Fed and the Bank of England purchased assets with a value of 13-16% of GDP within about a year, mainly in 2009.[1]

After the financial crisis, when the nominal short-term interest rates became constrained by the effective lower bound (ELB), asset purchases became the primary tool for major central banks to conduct monetary policy. After the financial crisis, the recovery of global economic activity was quite slow, despite the major central banks keeping interest rates close to zero. After several years, inflation in the major economies also decreased significantly, approaching zero. Therefore, under these conditions, asset purchases became the principal monetary policy instrument for supporting economic activity and inflation, with the aim of exerting a positive impact on the economy by lowering long-term interest rates. Asset purchase programmes were conducted in different periods by the Fed, the Bank of England, the Bank of Japan, the ECB and the Swedish Riksbank. The subject of purchases were mainly Treasury bonds, although mortgage securities (MBS and covered bonds), corporate bonds, and shares were also purchased. Some programmes featured a predefined horizon of the central bank activity (the United Kingdom, Sweden); however, more flexible open-ended programmes became common later, conducted without a defined end date but with a specified monthly scale (the ECB, the Fed in the third round of QE, the Bank of Japan in 2013-2016).[2] The extent of purchases was highly diversified, ranging from a dozen or so per cent of GDP in the USA, Sweden and in the United Kingdom to close to 100% of GDP in Japan.

Following the outbreak of the coronavirus pandemic, asset purchases began to be widely used to increase liquidity in financial markets and to support fiscal policy. In late February and early March 2020, a sudden sale of risky assets took place, reflected in declines of over 30% in major stock indices. In mid-March, the sell-off also extended to safe assets, including Treasury bonds, while many markets, including money and bond markets, ceased to operate efficiently. Under these conditions and faced with the need for unprecedented fiscal stimulus, asset purchases were launched not only by the major central banks, but also by the central banks of almost all the other developed economies and 28 emerging and developing economies (Fratto et al., 2020). Treasury bonds remained the main subject of the purchases. Many central banks, especially in emerging economies, initiated

[1] In Japan, the extent of purchases was much smaller (3.4% of GDP) and the duration of the first post-crisis phase of quantitative easing was longer (22 months) than in the United States and in the United Kingdom.

[2] In 2016, the Bank of Japan simultaneously launched a yield curve control programme targeted at the 10-year bond yield rather than the scale of purchases.

quantitative easing without specifying either the expected volume of the purchases or their termination date. This was consistent with the objectives of the purchases, targeted at increasing liquidity in the bond market. In many of these economies, central banks performed, in a way, the role of buyer of last resort and consequently the scale of their purchases was small. At the same time, in advanced economies, purchases were usually aimed at providing broad monetary stimulus in addition to supporting market operation. Therefore, quantitative easing programmes had a predefined time frame and also covered private assets, while their scale was relatively high.[3] Asset purchase programmes were also designed to support anti-crisis fiscal packages by creating appropriate conditions for their financing and reducing yields in the bond market (Joyce et al., 2010; Christensen and Gillan, 2019).

1.1 Asset purchase programmes transmission channels

The main effect of asset purchases by the central bank is easing funding conditions, primarily by lowering the longer end of the yield curve. In the literature, two main mechanisms of the impact of asset purchases on the easing of funding conditions are mentioned: the signalling channel and the portfolio channel (Borio and Disyatat, 2009).

Signalling channel. Central bank operations or information thereof influence the expectations of economic actors regarding the future monetary policy, the demand-supply relationship of assets, as well as the liquidity and risk of assets. These expectations significantly affect asset pricing. In particular, asset purchases should emphasise the central bank's determination and institutional and legal capacity to ease monetary conditions even after the lower bound on interest rates has been reached, which may contribute to lowering the path of expected short-term interest rates, putting downward pressure on the longer end of the yield curve.

Portfolio channel. When short- and long-term debt securities are imperfect substitutes, an increase in the demand for longer-term assets purchased by the central bank should have a downward effect on the term premium of these assets and, consequently, should lead to the yield curve flattening. Moreover, the impact of central bank operations on the structure of private sector portfolios also results in upward pressure on the prices of other assets (not only those purchased by the central bank). When the central bank buys assets, the amount of reserve money held

[3] At the same time, the pace of purchases among major central banks was markedly higher than during the financial crisis.

by entities increases. If the reserve money is not a perfect substitute for the assets sold, the sellers of assets may try to change the structure of their portfolios by buying other assets that are better substitutes for them.[4] This process triggers an increase in asset prices and continues until a balance is reached.

In addition to the two aforementioned major transmission channels of asset purchase programmes, the literature also mentions several other channels which are, however, interrelated. The first one is the credit channel. With an increase in the amount of reserve money on their balance sheets, commercial banks may be willing not only to buy assets that are better substitutes to those bought by the central bank, but also to increase the supply of credit to increase their risk exposure. The second additional channel is related to risk-taking. The easing of lending conditions and "cleansing" of portfolios of risky assets as a result of the central bank's actions may also increase banks' risk appetite.

Asset purchases by the central bank and the accompanying adjustments in financial markets, in particular the lowering of the longer end of the yield curve, may affect the economy in several ways. First, asset purchases reduce borrowing costs for households and firms, which may increase aggregate investment and consumer demand. Second, quantitative easing may contribute to a depreciation of the domestic currency, which leads to improved net exports. Third, quantitative easing can also push up the prices of other assets, including equities and, by increasing liquidity in the banking sector, encourage banks to grant credits. This fosters further improvements in the availability of finance and financing conditions, which may also translate into higher consumer and investment demand. Fourth, higher asset prices can also stimulate spending through the wealth effect (Joyce et al., 2011). Fifth, asset purchases contribute to raising inflation expectations, affecting a decline in the real interest rate, which may support the demand in the economy (Joyce et al., 2011). Sixth, quantitative easing lowers – *ceteris paribus* – the public debt servicing costs, which may encourage or facilitate more expansionary fiscal policy.

Taking into account the aforementioned transmission channels, asset purchases conducted by the central bank boost economy and accelerate inflation.

[4] Factors affecting the degree of asset substitutability include, among others, the maturity, credit risk, and liquidity.

1.2 Review of existing empirical studies on the macroeconomic effect of quantitative easing

The extensive empirical literature evaluating the effectiveness of quantitative easing programmes mostly indicates that asset purchases provide an effective tool to influence financial markets, the real economy and inflation.[5] Nevertheless, it should be stressed that estimates of the effects of asset purchases are subject to considerable uncertainty and depend on the method, sample, economic situation, financial market characteristics and assumptions made. In particular, asset purchases seem to be more effective during crises and in countries with more developed capital markets.

In the early years of asset purchases conducted by major central banks (when the length of the time series was limited), the event study method was mainly used to analyse the impact of asset purchases on bond yields and prices of other financial assets. This method involves examining how asset prices changed in a narrow time window after the central bank's decision regarding asset purchases. The first studies indicated the effectiveness of quantitative easing (decline in long-term interest rates), which was mainly due to the clear response of financial markets to the announcement of the first purchase programmes during the global financial crisis (among others, Gagnon et al. 2011, Krishnamurthy and Vissing-Jorgensen 2011, Lam 2011, Christensen and Rudebusch 2012, Joyce and Tong 2012, Bauer and Rudebusch 2014, Altavilla et al. 2015, Fukunaga et al. 2015, Andrade et al. 2016). However, the impact of subsequent asset purchase decisions seems weaker, perhaps because these decisions were more expected and no surprise effect occurred. However, some studies suggest that when the cumulative effect of all the monetary policy decisions during the asset purchase period is considered, the impact of asset purchases on bond yields is close to zero (Greenlaw et al., 2018).

On the other hand, three approaches are used to study the impact of quantitative easing on GDP and inflation. The first, theoretical approach, is based on general equilibrium models with calibrated parameters (e.g. Gertler and Karadi, 2013). The second approach relies on vector autoregression models (e.g. Kapetanios et al., 2012). The third approach is a two-step procedure involving the construction of the shadow policy rate, followed by an analysis of the impact of SPR changes on GDP and inflation.

The impact of quantitative easing on GDP and inflation is generally positive and simultaneously heterogeneous. Chung et al. (2012) indicate that lower long-term

[5] A detailed summary of empirical studies on the effects of quantitative easing is presented in Annex A.1.

interest rates, combined with higher equity valuations and the low value of the dollar, provided significant support to the US real economy. Quantitative easing of monetary policy by the FED until the second half of 2012 (peak effect) may have increased the level of US real GDP by almost 3% and the inflation rate by 1 percentage point. In turn, Kapetanios et al. (2012) show that the impact of a 100 basis point reduction in long-term bond yields following the implementation of the 1st phase of the quantitative easing policy pursued by the Bank of England (cf. Joyce et al., 2011) on real GDP may have approached approx. 1.5%, while the impact on annual CPI inflation may have been approx. 1.25 percentage points (peak effect). Therefore, it is possible that the QE policy helped the UK economy avoid a deeper recession and deflation.

Estimates of the impact of quantitative easing on GDP and inflation based on VAR models are, on average, higher than those based on DSGE models (Kapetanios et al. 2012, Baumeister and Benati 2013, Weale and Wieladek 2016, Hesse et al. 2018). An exception is the study for Japan, which shows a much smaller buyback effect (Schenkelberg and Watzka 2013). Studies using the VAR models also indicate the declining effectiveness of the successive rounds of quantitative easing (Hesse et al. 2018), which may have been associated with the improved financial conditions, and the increased effectiveness of Treasury bond purchases compared to purchases of mortgage securities (Weale and Wieladek 2016). However, the above results were mostly obtained when identifying shocks using the sign restriction method, which imposes *a priori* a significant impact of quantitative easing on bond yields, and using a small number of variables. When alternative methods of identifying shocks and more variables are used, the estimated effects tend to be smaller.

Moreover, the mere announcement of asset purchases which is ultimately not accompanied by their purchase may have an impact on the financial market situation and on the real economy. Altavilla et al. (2016) estimate the impact of information related to the announcement of the Outright Monetary Transactions (OMT) programme by the ECB on real GDP, the HICP inflation rate, and the value of credit. At the end of the 3-year projection period, the median of the impact of information concerning the OMT on real GDP amounted to 1.50% for Italy (2.01% for Spain), while the impact on HICP was 1.21% (0.74%), and on the value of loans to households and non-financial corporations – 3.58% (2.31%). The impact on the real economy of France and Germany was positive but much lower.[6] Although Altavilla et al. (2016) do not refer directly to the transmission channel of the OMT programme,

[6] Altavilla et al. (2016) indicate that information related to the ECB's announcement of the OMT programme resulted in a decline in the yields of 2-year government bonds of Italy and Spain to approx. 2.0 percentage points, whereas it had no significant impact on the corresponding yields of Germany and France.

its operation can be linked to the signalling channel since, despite potentially unlimited purchases, there were no interventions under it.

Quantitative easing most frequently contributes to depreciation of the exchange rate. Georgiadis and Gräb (2016) estimate that information related to the asset purchase programme (APP) announced by the ECB resulted in a 6.4% depreciation of the nominal effective exchange rate of the euro (cumulative value), and an 8.4% depreciation of the euro against the US dollar. According to Georgiadis and Gräb (2016), the depreciation of the euro was driven by a decline in real interest rates in the euro area in the face of expectations of monetary policy normalisation in the United States (a possible reinforcement of the divergence of monetary policy cycles), while the pressure on the euro depreciation was consistent with the operation of the signalling channel. Juxtaposing the effects of APP-related information with the effects of Securities Market Programme (SMP) announcements in 2010 and 2011 and OMT in 2012 indicates that only APP-related information had an immediate and significant impact on the euro exchange rate. In turn, Dedola et al. (2020) estimate that a 20% increase in the ECB balance sheet relative to the Fed balance sheet leads to a depreciation of the euro against the dollar of approx. 7%. The strongest depreciation (0.35%) occurs after 9 months. Depreciation is statistically significant up to 18 months. The increase in the assets ratio (ECB versus Fed) leads to the depreciation of the euro against the dollar mainly by reducing short-term interest rate differentials between the euro area and the US money markets and by reducing the exchange rate risk.

2. Macroeconomic context

This section presents the macroeconomic condition of the Polish economy on the eve of the COVID-19 pandemic. Next, the characteristics of the pandemic shock and the response of the Polish economy to the pandemic are discussed.

2.1 The Polish economy before the COVID-19 pandemic

The balanced character of the Polish economy before the COVID-19 pandemic facilitated effective countercyclical fiscal and monetary policies. In the hypothetical case of the presence of significant macroeconomic imbalances, the pursuit of active fiscal or monetary policy may lead to an increase in these imbalances in the economy. For example, a high level of general government debt may be associated with a high debt servicing cost, jeopardising the countercyclical fiscal policy. On the other hand, external and internal balance of the economy significantly reduces the risk of sudden capital outflows, which creates space for monetary policy.

Relatively high economic growth and low unemployment, accompanied by moderate inflation and lending growth, point to the absence of significant internal imbalances. In 2019 Q4, GDP growth amounted to 3.6% y/y, and although it slowed down slightly (Figure 1), it remained markedly higher than in Western Europe. It was accompanied by favourable situation of employees on the labour market, which was reflected in the lowest unemployment rate since the beginning of the economic transition (Figure 1). Favourable economic conditions were not associated with high price pressure, as illustrated by inflation remaining close to the inflation target throughout 2019 (2.3% y/y against the target of 2.5% ± 1 percentage point). Although price growth picked up just before the pandemic (to 4.7% y/y in February 2020; Figure 1), it resulted mainly from regulatory and supply-side factors.[7] At the same time, private non-financial sector debt remained relatively low compared to other countries of Central and Eastern Europe and advanced economies, while its growth rate was slightly lower than nominal GDP growth (Figure 1).

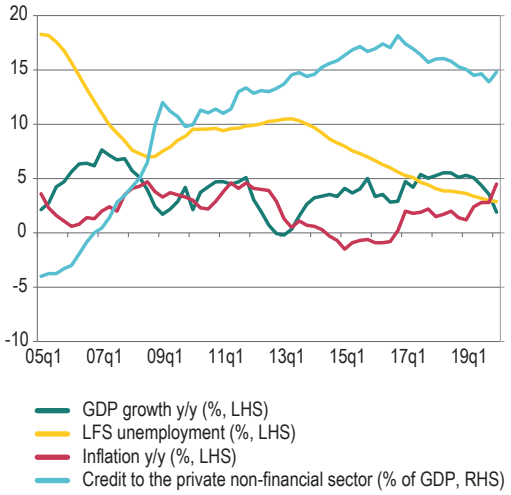
The condition of the public finance and financial sectors in Poland also indicated the absence of significant internal imbalances. Both a small deficit (0.7% of GDP according to ESA in 2019) and a relatively low level of public debt (46%, Figure 3) indicate that the condition of the public finance sector was relatively good. In turn,

[7] These include increased electricity prices and waste disposal fees, increased excise duty on cigarettes and alcohol, and increases in meat prices as a result of the ASF epidemic.

high capital position and high profitability of banks prove that the financial sector was stable. Moreover, the credit risk assessment did not raise any concerns, while the overall quality of the loan portfolio remained stable. Liquidity risk was also low, as indicated by supervisory liquidity ratios and the banks' holdings of liquid assets.

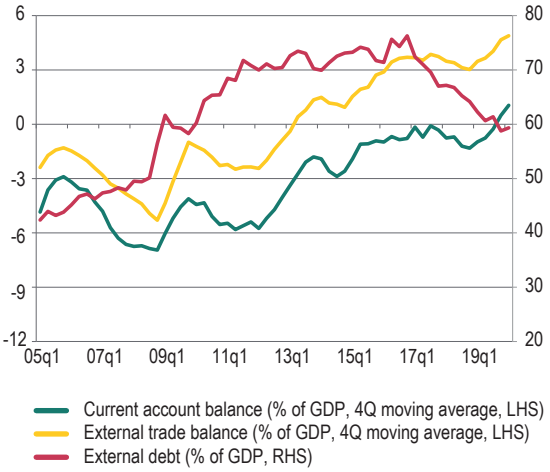
Internal balance was accompanied by external balance. The current account balance was close to zero (0.5% of GDP in 2019) and the external trade balance was clearly positive (4.7% of GDP). The latter has significantly improved over recent years, mainly due to growing exports of services, primarily transport and business services. This has been fostered by relatively high price and cost competitiveness of Poland. At the same time, the level of external debt has been decreasing (Figure 2).

Figure 1 Internal balance indicators before the COVID-19 pandemic (until 2020 Q1)



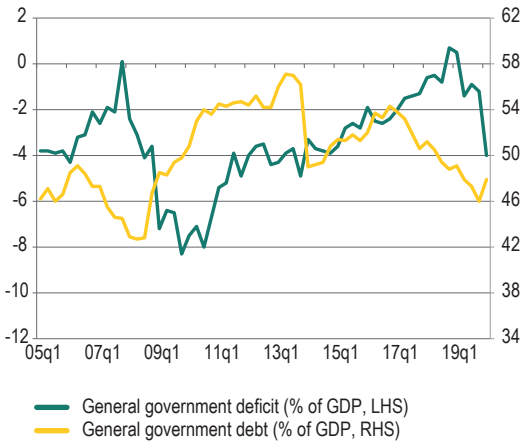
Source: Statistics Poland and ECB data.

Figure 2 External balance indicators before the COVID-19 pandemic (until 2020 Q1)



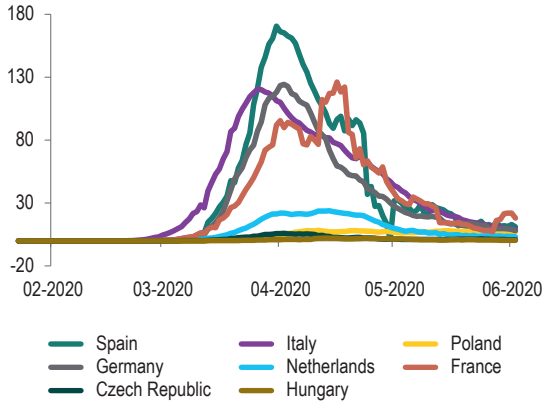
Source: NBP data

Figure 3 Fiscal condition indicators before the COVID-19 pandemic (until 2020 Q1)



Source: Eurostat data.

Figure 4 Daily number of diagnosed SARS-CoV-2 infections per 1 million inhabitants in selected EU countries in the first half of 2020 (7-day average)



Source: Bloomberg and Eurostat data, own calculations.

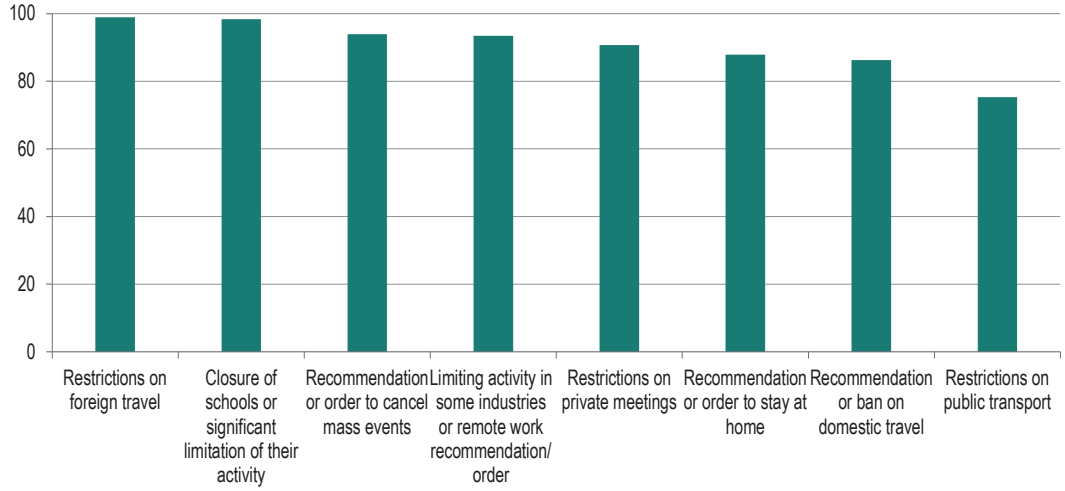
2.2 Characteristics of the global pandemic shock

The COVID-19 pandemic resulted in the deepest global recession since at least the Second World War. From late 2019 to mid-2020, global GDP decreased by approx. 10%, and recession occurred in the vast majority of countries worldwide. The pandemic shock affected the economy through various channels, related to both supply and demand, while its strength and degree of synchronisation between the economies was unprecedented.

The COVID-19 pandemic broke out in early 2020. At the turn of 2019 and 2020, the first cases of people infected with the new SARS-CoV-2 coronavirus were detected in China. In February, the epidemic also broke out on a large scale in Italy, after which the virus reached almost every country worldwide, while on 11 March 2020, the World Health Organisation officially declared the COVID-19 pandemic and the number of daily infections worldwide gradually increased in the subsequent months of 2020.

To curb the rapid spread of the SARS-CoV-2 virus, the governments of the majority of countries worldwide imposed epidemic restrictions, the extent of which varied over time and between countries (Figure 5,
Figure 6). Widely used restrictions included: the temporary closure of schools and retail and service outlets in some industries, as well as restrictions on leaving home without a significant reason. In turn, many industries where the economic activity was not suspended operated under a strict sanitary regime, while their operations were subject to restrictions based on so-called social distancing rules.

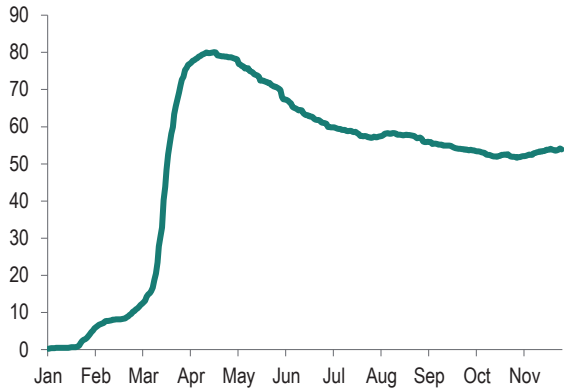
Figure 5 Percentage of countries in the world where the specified sanitary restrictions were introduced in response to the COVID-19 pandemic (%)



The data cover 182 countries worldwide for the period from 1 January 2020 to 30 November 2020.

Source: Oxford Coronavirus government response tracker data.

Figure 6 Average severity of epidemic restrictions in 182 countries worldwide (Oxford Stringency Index)



Source: Oxford Coronavirus government response tracker data.

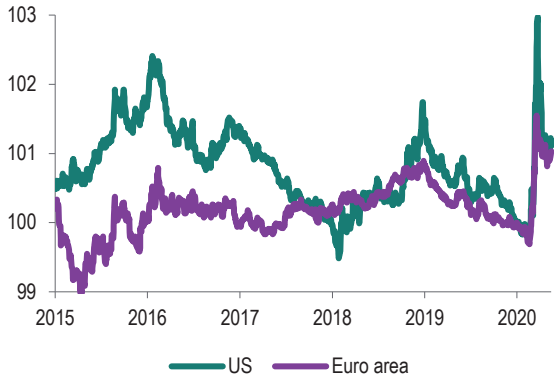
The COVID-19 pandemic and the resulting preventive measures have affected the global economy through a number of channels, including those on the supply side. A direct consequence of the restrictions was a decline in production in the sectors affected. The supply side of the economy was also negatively affected by the pandemic through the temporary disruption of global supply chains and the decline in labour productivity associated with epidemic restrictions.

At the same time, aggregate demand was negatively affected by the epidemic as well as by the related restrictions and uncertainties, among others, through constraints on consumption, deterioration in consumer sentiment, and worsening

of the labour market conditions. In addition to complying with epidemic restrictions, consumers and enterprises limited their mobility on a voluntary basis, which had a further adverse impact on demand (IMF, 2020a). At the same time, the current and expected situation of employees in the labour market deteriorated. Companies which cease or reduce their operations decrease orders and often decide to cut staff and wages. Moreover, a decline in consumption of goods complementary to those directly affected by the restrictions is recorded (Guerrieri et al. 2020). In this way, the initial supply shock quickly triggers a strong simultaneous demand shock.

High uncertainty was an important factor limiting the scale of economic activity amidst the COVID-19 pandemic (Beker et al., 2020). It was mainly related to the continued development of the epidemic and its effects, both in terms of public health and the economy. Growing concerns of losing a job or deteriorating employment conditions increased households' propensity to save, negatively affecting consumption.[8] At the same time, many companies, due to enormous uncertainty, reduced investment, especially in industries most vulnerable to the effects of the pandemic and the sanitary restrictions.

Figure 7 Goldman Sachs Financial Conditions Index (index, 01.01.2020 = 100)



Source: Bloomberg data.

An increase in the index indicates tightening of the financial conditions.

The pandemic shock was accompanied by dramatic tightening of financing conditions worldwide. In the initial phase of the spread of the epidemic, a marked

[8] Macroeconomic data for the quarters following the outbreak indicate that an important part of consumer demand was deferred until the epidemic restrictions were relaxed, which supported a relatively robust recovery of economic activity in many countries.

decline in share prices was recorded, accompanied by a rise in risk premiums and capital outflows from emerging markets (Figure 7).[9]

Against this background, global GDP decreased between 2019 Q4 and 2020 Q2 by approx. 10% (OECD 2020a; Figure 8). This was accompanied by a sharp decline in the value of world exports (Figure 9). The deepest downturn in activity was seen in April, when industrial production and retail sales fell by more than 20% in advanced economies (Figure 10). Information available at the end of 2020 indicates that the decline in global GDP in 2020 was the deepest at least since World War II (Figure 11).

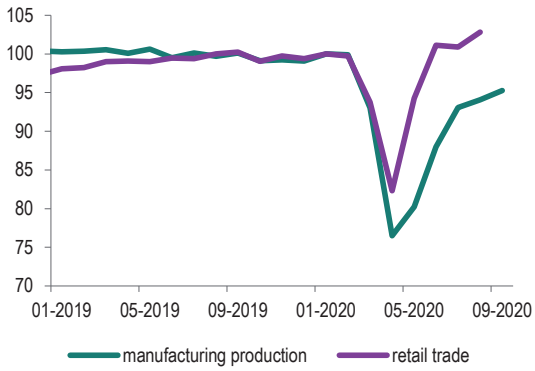
Figure 8 World GDP growth (% y/y)

Source: Bloomberg data, Eurostat and IMF, own calculations.

Figure 9 World export growth (% y/y)

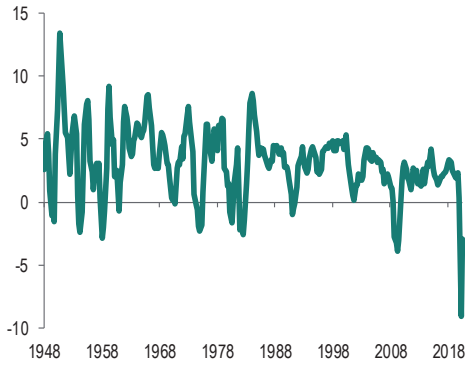
Source: Centraal Planbureau data.

Figure 10 Economic activity indices in OECD countries (index, January 2020 = 100)



Source: OECD data.

Figure 11 Year-on-year GDP growth in the United States (quarterly data, %)



Source: Fed data.

[9] In the consecutive months, global equity prices rose while the premium for risk fell, most- likely affected by the marked loosening of the monetary and fiscal policy in most economies, although volatility in the financial markets remained higher than before the pandemic.

A characteristic feature of the economic developments following the pandemic shock was the relatively rapid recovery in activity (Figure 14)**. However, its sustainability depends largely on the epidemic situation**. As some restrictions were lifted, activity started to pick up noticeably from May onwards, with global GDP increasing in 2020 Q3 compared to the first half of the year. The dynamic recovery of economic activity was supported by the strong easing of the fiscal and monetary policy in response to the pandemic in most of the world's major economies. However, in 2020 Q4, with the emergence of the subsequent wave of infections in many developed economies and the reinstatement of the significant part of the restrictions, activity declined again.

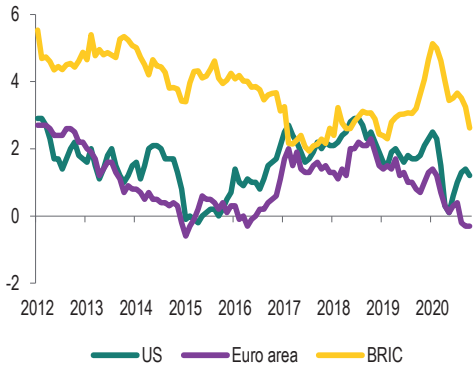
The collapse in global economic activity following the pandemic shock was accompanied by a decline in inflation in many countries. Due to the drop in demand, prices of energy commodities, especially crude oil (Figure 12), and agricultural commodities fell sharply. As the demand for consumer goods slowed down in many economies, especially in developed countries, core inflation also declined. Consequently, in the first months of the pandemic, the global price growth of consumer goods and services dropped and some countries experienced deflation (Figure 13).[10]

[10] It should be noted, however, that during the pandemic – especially when far-reaching epidemic restrictions were in place – measuring inflation became challenging, since the prices of many goods became unobservable; moreover, the fixed weights in the basket of consumer goods did not take into account pandemic-induced changes in consumption patterns.

Figure 12 Brent crude oil price (USD/barrel)

Source: Bloomberg data

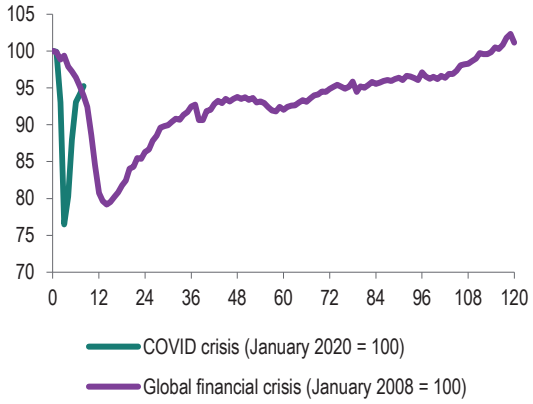
Figure 13 Inflation in the United States, the euro area and in the BRIC economies



Source: Bloomberg data, IMF.

BRIC - average GDP-weighted inflation in Brazil, Russia India and China.

Figure 14 Manufacturing production in OECD countries in the aftermath of the COVID-19 pandemic and after the outbreak of the 2008 global financial crisis (monthly, seasonally-adjusted data)



Source: OECD data

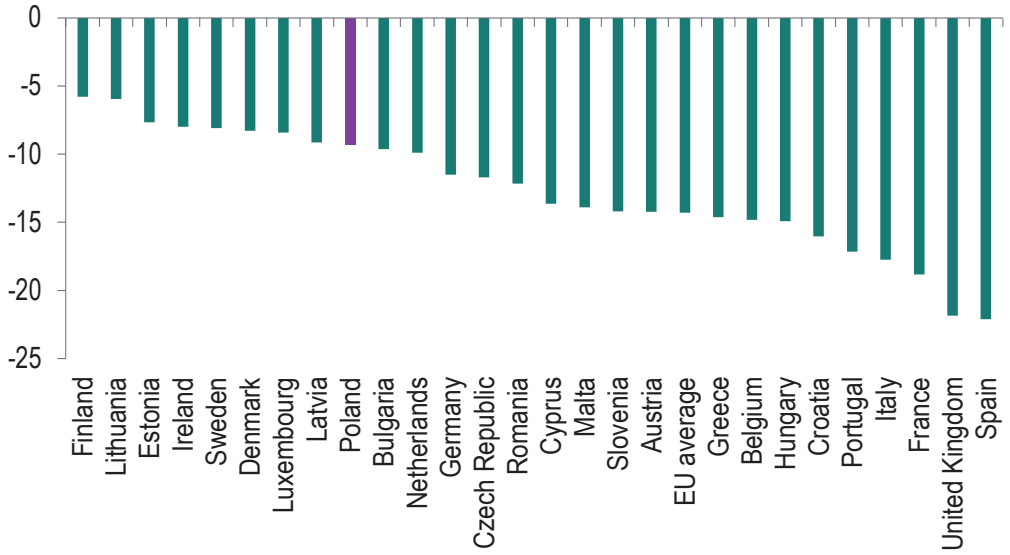
2.3 The Polish economy in the first months of the COVID-19 pandemic

The COVID-19 epidemic also spread in Poland; therefore, sanitary restrictions were introduced in order to limit the spread of the virus. In Poland, the first case of SARS-Cov-2 virus infection was reported in early March 2020. In the following months, the number of infections increased; however, the epidemic situation in Poland in the first half of 2020 was better than in many other EU countries (Figure 4).

In March and early April 2020 many sanitary restrictions were introduced (which were then gradually eased or lifted)[11]:

The COVID-19 epidemic and the associated sanitary restrictions led to a sharp decline in economic activity in Poland. Overall, in the first half of 2020, GDP fell by 9.3% (Figure 15). It was by far the deepest recession in Poland since the economic transition of the 1990s. Nevertheless, the scale of the recession was much smaller than in the majority of the European economies, as illustrated by the fact that GDP of the EU countries in the first half of 2020 fell by 14.3% on average (Figure 15). Among individual economic sectors, the strongest decline in value added in the first half of 2020 was recorded in the service sectors most vulnerable to the effects of the epidemic and the sanitary restrictions – accommodation and catering, entertainment, recreation and culture, and passenger transport.

Figure 15 GDP decline from 2019 Q4 to 2020 Q2 (%)

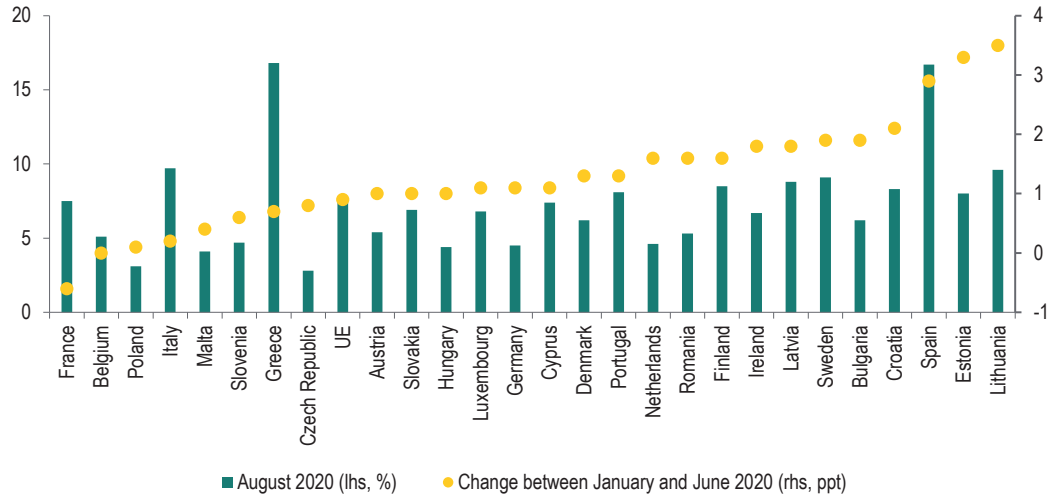


Source: Eurostat data.

[11] Among others, the following restrictions were introduced: cinemas, theatres and other cultural establishments, hair and beauty salons, hotels, accommodation places and restaurants (takeaways remained permitted) as well as most service outlets and shops in shopping centres were closed; the maximum number of customers allowed in retail or service outlets was restricted; schools and other educational establishments were closed; all mass events were cancelled; international air traffic was suspended and border controls and restrictions were introduced on the entry of foreigners to Poland; restrictions were introduced on movement and the operation of public transport; a requirement for quarantine following a suspected contact with a person infected with the virus was introduced; the sanitary rules of work organisation were tightened; rehabilitation treatments were suspended; restrictions on assemblies in public places were introduced; restrictions concerning leaving the house were introduced.

Situation in the labour market also deteriorated. In the first half of 2020, employment and the number of working people decreased, the number of people economically inactive increased and wage growth slowed down. The unemployment rate also increased, although to a limited extent, significantly less than in many EU countries (Figure 16).

Figure 16 Unemployment rate (seasonally-adjusted data, %)



Source: Eurostat data.

Following the outbreak of the COVID-19 pandemic, consumer price growth in Poland decreased. The decline in fuel and food prices contributed to the fall in inflation in the first months after the outbreak of the pandemic, due to the decline in global commodity prices, especially crude oil prices. On the other hand, rising prices of some services, including medical services and communications, which may have been influenced by the development of the epidemic, had a positive impact on inflation growth. At the same time, regulated electricity and waste disposal fees and excise goods prices had a strong positive contribution to inflation in annual terms in the first half of 2020.

In response to the economic shock of the COVID-19 outbreak and the administrative restrictions introduced, the government implemented a broad anti-crisis fiscal package. At the beginning of April 2020[12], measures were launched

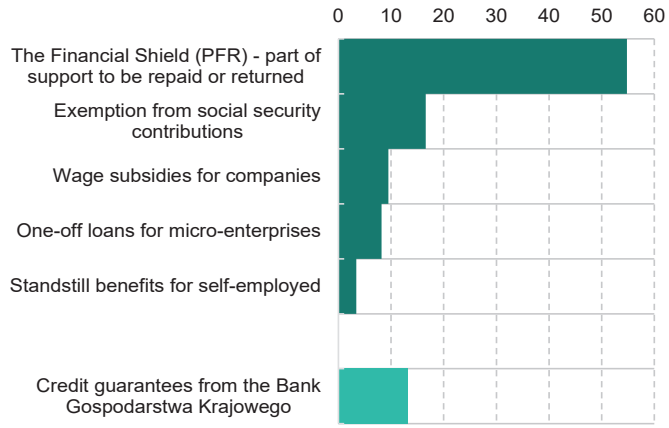
[12] Act of 31 March 2020 amending the Act on special solutions related to the prevention, counteracting and combating of COVID-19, other infectious diseases and crisis situations caused by them, as well as some other acts (Journal of Laws of 2014, item 568, as amended).

under the so-called anti-crisis shield, extended in subsequent weeks[13], aimed primarily at supporting economic entities. This support primarily included partially non-refundable[14] subsidies provided under the Financial Shield implemented by the Polish Development Fund (Polski Fundusz Rozwoju S.A. – PFR), exemptions from paying social security contributions, wage subsidies, loans to micro-entrepreneurs and standstill benefit for the self-employed and persons employed under civil law contracts. The total amount of assistance for firms (including BGK credit guarantees) reached approx. PLN 106 billion in 2020 Q2 (i.e. approx. 4.6% of GDP, Figure 17). Following the restrictions in economic activity and the launch of the government's anti-crisis shield, the general government balance (ESA2010) and the public debt-to-GDP ratio deteriorated markedly in 2020 Q2. (Figure 19). Throughout the first half of 2020, the headline deficit (ESA 2010) amounted to approx. 4.3% of the full-year GDP, of which approx. 3% of GDP resulted from the anti-crisis measures taken by the government in response to the epidemic. These measures were associated with a high increase in borrowing needs in the first half of 2020. Public debt in ESA2010 terms increased from PLN 1,045.4 billion at the end of 2019 to PLN 1,256.0 billion at the end of June 2020. (Figure 19).

[13] Cf., among others, the Act of 16 April 2020 on special support instruments in connection with the spread of the SARS-CoV-2 virus (Journal of Laws item 695), Resolution No. 50/2020 of the Council of Ministers of 27 April 2020 on the government programme "Financial Shield of the Polish Development Fund for micro, small and medium-sized companies", Resolution No. 51/2020 of the Council of Ministers of 27 April 2020 on the government programme "Financial Shield of the Polish Development Fund for large enterprises", Act of 14 May 2020 amending certain acts in the field of protective measures in connection with the spread of the SARS-CoV-2 virus (Journal of Laws item 875), Act of 19 June 2020 on subsidies to interest on bank loans to entrepreneurs affected by COVID-19 and on simplified proceedings for the approval of an arrangement in connection with the occurrence of COVID-19 (Journal of Laws item 1086).

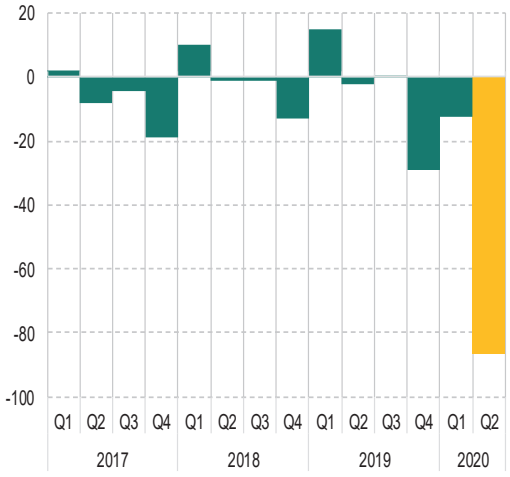
[14] In total, the limit of support under the PFR Financial Shield was set at PLN 100 billion, of which the support for micro-, small and medium-sized companies amounts to PLN 75.0 billion (preferential financing with a possibility of cancellation of up to 75% of the loan granted), while the support offered to large companies amounts to PLN 25 billion (liquidity loans, equity injections, preferential financing with a possibility of cancellation of up to 75% of the loan granted – a limit of PLN 7.5 billion).

Figure 17 Support to enterprises under the so-called government anti-crisis shield in 2020 Q1 and Q2 (PLN billion)



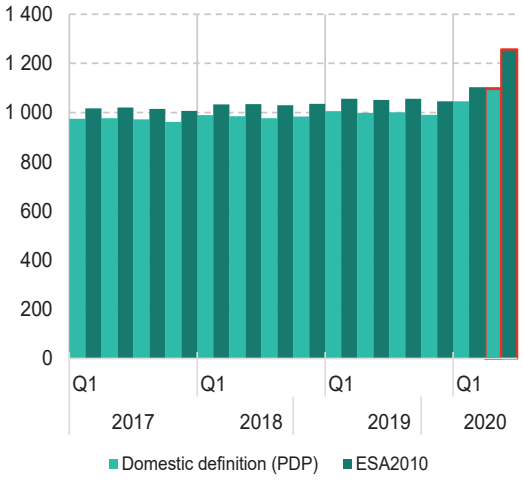
Source: Social Insurance Institution (ZUS), Ministry of Family and Social Policy, Ministry of Development, Labour and Technology, Polish Development Fund.

Figure 18 General government balance (ESA2010), on a quarterly basis (PLN billion)



Source: Eurostat.

Figure 19 Public debt, as at the end of the period (PLN billion)



Source: Eurostat, Ministry of Finance.

3. Characteristics of the Structural Open Market Operations programme

In this section of the paper, the key characteristics of the SOMO programme are discussed.

3.1 Announcement, objectives and design

NBP announced its intention to purchase Treasury bonds in the secondary market on 16 March 2020, while on 8 April 2020 the purchases were extended to include securities guaranteed by the State Treasury. On 16 March 2020, the NBP Management Board announced the implementation of large-scale purchases of Treasury bonds in the secondary market as part of the structural open market operations (SOMO). A very similar statement was included in the "Information after the meeting of the Monetary Policy Council" issued a day later, on 17 March. On 8 April, the Monetary Policy Council (MPC) extended asset purchases to include other Treasury securities and debt securities guaranteed by the State Treasury.

The SOMO aims at improving liquidity in the banking sector and in the bond market and strengthening the monetary policy transmission mechanism. NBP has indicated three objectives for the SOMO: (i) to change the long-term liquidity structure in the banking sector; (ii) to ensure liquidity in the secondary market for repurchased securities; (iii) to enhance the impact of the NBP interest rate cuts on the economy, i.e. to strengthen the monetary policy transmission mechanism. Similar objectives (ensuring the smooth functioning of markets, improving liquidity) are indicated by 30 out of 40 central banks conducting asset purchases during the pandemic (Fratto et al., 2020).

A characteristic feature of the SOMO is its flexibility regarding the scale and pace of asset purchases. The SOMO programme is open-ended, i.e. no termination date has been announced. At the same time, the scale of the purchases has been announced neither in aggregate terms nor on a monthly or weekly basis.[15] As indicated by the Monetary Policy Council in the "Information after the meeting" press releases, the timing and scale of the operations conducted depend on market conditions. A similar practice is applied by many other central banks, especially in

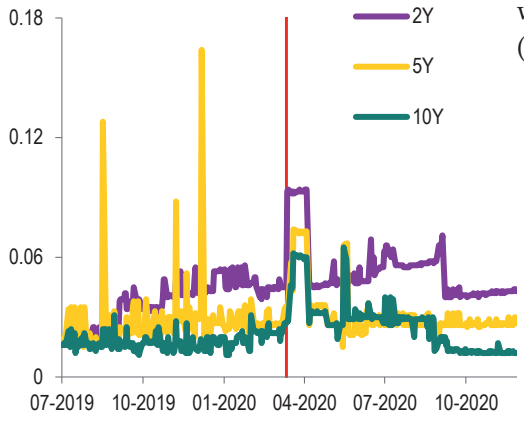
[15] The press release of 30 April indicated that "The target scale of the NBP programme of selected debt securities purchases has not been specified. Such operations will be continued until further notice [...]".

emerging economies, including the countries of Central and Eastern Europe (Hungary, Croatia, Romania).

SOMO operations are conducted through auctions. The first bond purchase auction was held on 19 March. From April to July the auctions were held twice a month and from August onwards – once a month. Before each operation, the maximum permissible scale (pool) and the set of bond series available for purchase is communicated. Most other central banks, especially in economies with relatively less developed capital markets, also purchase assets through auctions.

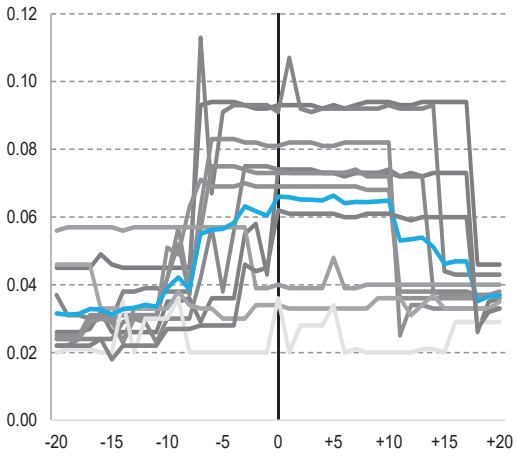
Following the launch of the SOMO, liquidity measures in the secondary bond market improved. Amidst stress in global financial markets at the beginning of the pandemic, liquidity in Polish government bond market decreased, which was reflected in a substantial widening in bid-ask spreads. In the following weeks – amid certain stabilisation in global financial markets coupled with anti-crisis measures, including the SOMO launched by NBP – bid-ask spreads has narrowed, indicating an increase in market liquidity (Figure 20). In particular, bid-ask spreads of the bonds series that were purchased by NBP as a part of SOMO, on average, stopped widening at the day of the auction on which they were purchased by NBP for the first time, and then the spreads narrowed over the next 20 days (Figure 21).

Figure 20 Bid-ask spreads of Polish government bonds (percentage points)



Source: Bloomberg data.
Red line denotes the beginning of the COVID-19 pandemic according to the WHO.

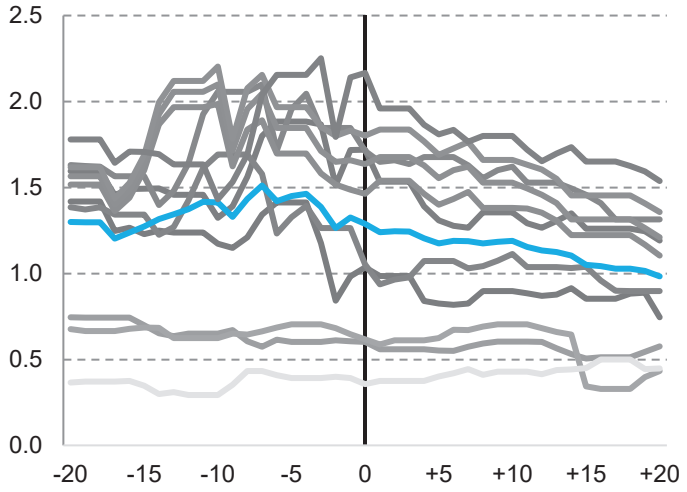
Figure 21 Bid-ask spreads of government bonds series being purchased by NBP as a part of SOMO within 20 days before and after the auction (percentage points)



Source: Bloomberg data.
The grey lines indicate bid-ask spreads of the specific bonds series. The blue line indicates arithmetic average of these spreads. The black line indicates the day of the SOMO auction. The horizontal axis indicates the number of days before and after the auction on which the bond series were purchased by NBP for the first time. Auctions between March and November 2020 are included.

It is difficult to assess the impact of the SOMO announcement on asset prices due to the timing of the announcement and concurrent interest rate cuts. The announcement of the NBP Management Board of 16 March was released after the end of the trading day. In this announcement, the Management Board also communicated other measures and recommended that the Council should reduce interest rates. On 17 March, at the opening, the yields on Treasury bonds did not change significantly and the zloty depreciated against the euro by 1%. During the day, however, bond yields were gradually decreasing – consequently, the yield on 10-year securities at the closure was 46 bps lower than the day before. However, this was affected by the MPC's afternoon decision to cut the reference rate by 0.5 percentage points and improved sentiment on the global financial markets.[16] The MPC's decision of 8 April to extend the SOMO was also accompanied by a 0.5 percentage point cut in the reference rate. The market response to this decision was less significant, with yields on 10-year Treasury bonds falling by 12 bps at the time of the announcement and the zloty depreciating against the euro by 0.4%. Also, yields on the specific government bonds series that were purchased by NBP in a given SOMO operation decreased (Figure 22).

Figure 22 Yields on government bond series purchased by NBP as a part of SOMO within 20 days before and after the auction (per cent)



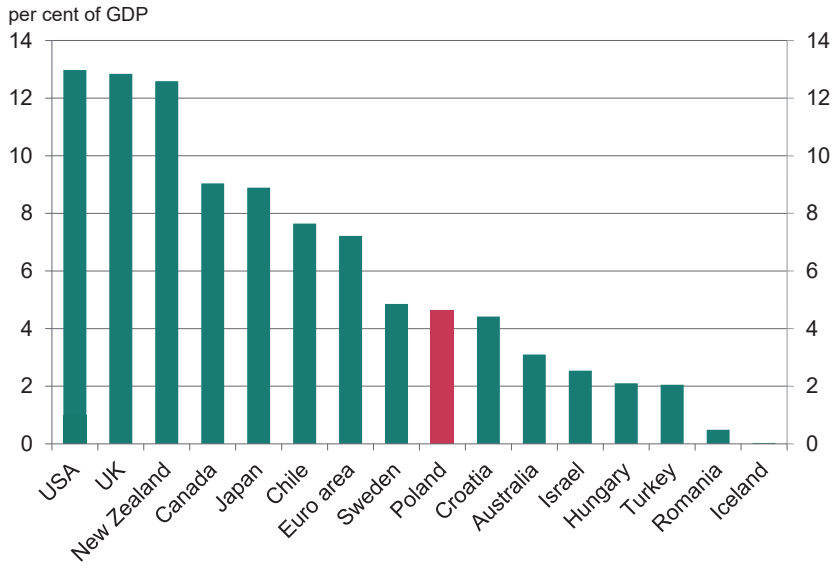
Source: Bloomberg data.
The grey lines indicate yields on the specific bonds series. The blue line indicates arithmetic average of these yields. The black line indicates the day of the SOMO auction. The horizontal axis indicates the number of days before and after the auction on which the bond series were purchased by NBP for the first time. Auctions between March and November 2020 are included.

[16] On 17 March, yields on 10-year Czech and Hungarian securities fell by 15-20 bps.

3.2 The scale and structure to date

The scale of the SOMO purchases until 18 November 2020 amounted to 4.6% of GDP and 11.7% of the market for purchased securities. Up to that point, NBP purchased securities with the nominal value of PLN 105.5 billion, representing 4.6% of 2019 GDP. NBP's share in the total market of securities subject to the SOMO[17] amounted to 11.7% in November, with a much smaller share in the Treasury securities market (7.1%) than in the markets of Treasury-guaranteed COVID-19 Response Fund BGK bonds (37.0%) and PFR bonds (30.4%).

Figure 23 Scale of asset purchases in selected economies beginning at the end of February 2020



Source: central banks' and OECD data.
For Romania, New Zealand, Chile, Israel and Iceland, data up to September 2020, for all other countries - up to October. GDP for 2019.

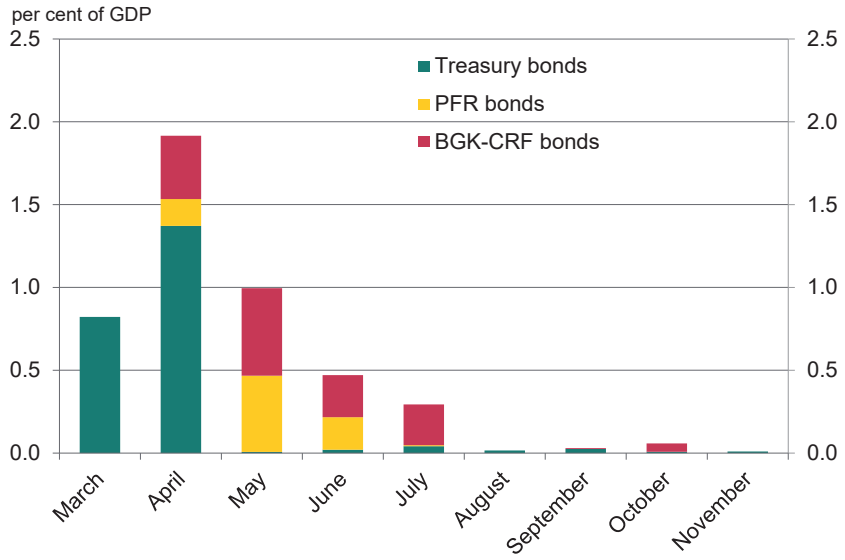
Compared to other economies, the scale of asset purchases by NBP has so far been close to the average for the pandemic period (Figure 23)**.** At the same time, the scale of asset purchases in Poland was smaller than in the majority of advanced economies, which is understandable given a lower level of public debt and lower degree of capital market development (thus, a smaller stock of public and private assets). At the same time, however, it was higher than in the majority of emerging economies, which, on the one hand, may be associated with the relatively high credibility of

[17] Marketable domestic Treasury securities and Treasury-guaranteed COVID-19 Response Fund BGK bonds and PFR bonds.

Poland in comparison with this group of countries and, on the other hand, indicates that the NBP's response to the pandemic has been strong.

The vast majority of purchases had been completed by the end of July, whereas initially Treasury bonds were the subject of purchases, followed primarily by securities guaranteed by the State Treasury (Figure 24). By the end of July 2020, securities with the value equivalent to 4.5% of GDP were purchased, while in subsequent months the scale of purchases was relatively small. Treasury bonds were mainly bought in March and April and account for half of the portfolio of securities purchased until November. Other securities include State Treasury-guaranteed COVID-19 Response Fund bonds issued by Bank Gospodarstwa Krajowego (BGK) and bonds of the Polish Development Fund (PFR), which account for 32% and 18% of the portfolio of the assets purchased, respectively, and were mainly bought between April and July.

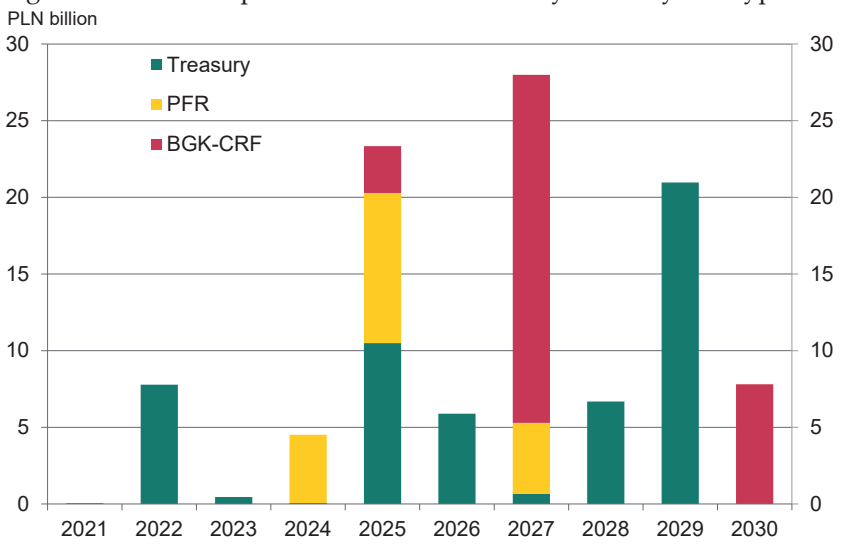
Figure 24 Scale of SOMO operations in individual months by type of securities



Source: NBP.

SOMO asset purchases have so far been concentrated in the segment of 5-to-10-year bonds (Figure 25). Consequently, the current average maturity of the securities bought stands at 6.3 years and is higher than for the overall market for assets subject to the SOMO (4.5 years).

Figure 25 Securities purchased under SOMO by maturity and type



Source: NBP.

Purchases completed by 18 November 2020.

Among Treasury securities, mainly fixed coupon bonds (DS, PS and WS series) **have been purchased under SOMO so far**. Zero-coupon bonds (OK series) have been bought on a smaller scale. Treasury bills, variable coupon bonds (WZ series) and inflation-indexed bonds (IZ series) have not yet been included in the SOMO programme.

4. Methodology for assessing the macroeconomic impact of SOMO

A macroeconomic evaluation of the impact of SOMO on the Polish economy is only possible using the counterfactual approach, which will enable an *ex-ante* evaluation. In the absence of a sufficiently long series of historical observations describing unconventional monetary policy, an *ex-post* evaluation, which is usually based on direct impact estimates, is impossible. Therefore, only an *ex-ante* evaluation of this phenomenon is feasible.

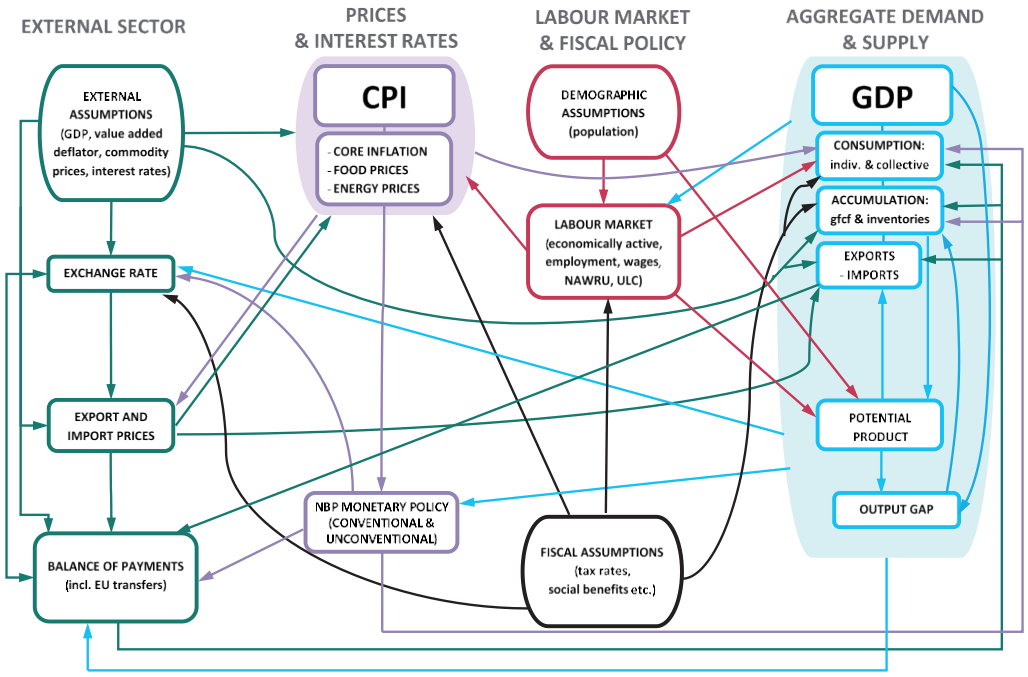
A counterfactual analysis aimed at identifying the magnitude of the SOMO impact on the Polish economy is based on a comparison of three scenarios. The first scenario is the baseline, which counterfactually assumes that the reference rate cuts did not take place and that no bond purchase programme was conducted by NBP. It corresponds to a hypothetical lack of response of conventional and unconventional monetary policy to the pandemic shock. The second scenario assumes the interest rate decreases close to the actual changes in the NBP reference rate in the first three quarters of 2020, with a total reduction of 1.4 percentage points relative to the baseline scenario. Based on a comparison of this variant with the counterfactual scenario, it is possible to assess the effect of conventional monetary policy tools, i.e. interest rates. The last scenario, on the other hand, corresponds to the actual response of NBP to the pandemic shock. This variant takes into account both conventional monetary policy tools and the launch of the SOMO programme.

The key scenarios were constructed for a relatively short time horizon. The simulation covers the period from 2020 Q2 to 2021 Q4. However, such a short horizon of analysis allows for an assessment of the impact of the unconventional monetary policy due to the fact that the maximum effect of the existing quantitative easing programmes is observed approximately 3 quarters after their launch (see Weale and Wieladek, 2016). It should also be borne in mind that the assessment of the impact is based on a comparison of the scenarios, which makes the estimates of the impact of SOMO independent of the availability of more recent data.

The NECMOD model was used to analyse the impact of the SOMO on key macroeconomic variables. The NECMOD model is a macro-econometric, multi-equation structural model used for forecasting economic developments in Poland and for scenario simulations. With its high degree of detail, the model incorporates a number of equilibrium mechanisms between key areas of the economy, i.e.

monetary policy, the corporate sector, households, the labour market, fiscal policy and foreign sector (see Figure 26).[18]

Figure 26 The NECMOD model structure



Source: NBP.

To analyse the impact of unconventional monetary policy in detail, the simulations take into account changes in the short-term interest rate implied by changes in the yield curve as well as the market effect of the bond purchase programme on the exchange rate. The scope of these modifications is related to the nature of macro-econometric models of the same class as NECMOD, i.e. the absence of mechanisms describing explicitly the programmes of bond purchases by the central bank. Therefore, a popular strategy is to include additional estimates of key macroeconomic variables that reflect the direct effect of monetary policy (see Chung et al., 2012). An alternative strategy would consist of a fundamental modification of the NECMOD model by adding a block of equations describing explicitly the tools of non-standard monetary policy. However, such a modification would entail a high degree of uncertainty regarding the parameters determining the effectiveness of this policy, which results from the lack of sufficiently long historical series enabling the estimation of key parameters.

[18] Descriptions of subsequent versions of the NECMOD model can be found on the NBP website: https://www.nbp.pl/home.aspx?f=/polityka_pieniezna/dokumenty/necmod.html.

The use of the counterfactual short-term interest rate reflecting changes in the yield curve makes it possible to consider a wide range of channels for the impact of unconventional monetary policy (cf. Chapter 1.1). Particular non-standard monetary policy instruments affect interest rates through different channels, while the strength of their impact varies depending on the maturity. While a conventional change in central bank interest rates has the strongest impact on short-term interest rates, in the case of forward guidance the strongest effect occurs for medium-term maturities, while the introduction of quantitative easing has the strongest effect on long-term rates (Swanson, 2018). Consequently, under ELB (Effective Lower Bound[19]) conditions, the use of a single observed interest rate with a selected maturity is a major simplification, since its level would only provide a part of the information about the scale of the non-standard monetary policy (cf. De Rezende and Ristiniemi, 2020).

Changes in the implied interest rate were estimated using the shadow policy rate (SSR) concept. It consists in estimating the value of an unobservable short-term interest rate whose changes would correspond to the shifts in long-term interest rates (yield curve) caused by unconventional central bank measures. This rate, unlike the official short-term central bank rates, would not have a lower limit imposed by the ELB and its level would depend on non-standard central bank measures (including the volume of purchases of debt securities or the use of forward guidance). In a purely conventional monetary policy environment, SSR estimates are therefore close to the value of the official short-term interest rates, but in the period when the central bank actively uses non-standard instruments, the SSR may assume negative values, which illustrates the impact of these instruments on the yield curve.

SSR estimates for Poland were obtained based on the method proposed by Krippner (2015).[20] This approach uses data on the yield rates of a specific risk-free financial instrument (such as zero-coupon bonds) for the available spectrum of maturities. In the case of Poland, time series from the Bloomberg database were used, referring to the daily PLN zero rates for the maturities of 3 and 6 months and 1, 2, 3, 4, 5, 7, 10 years, as of 2008. In addition, this method explicitly assumes the existence of a floor for nominal interest rates (ELB), which in the case of Poland will be at a level close to zero (0.05%), constant over time. The introduction of the ELB corresponds to the fact that official nominal interest rates do not usually fall below this value. Consequently, when the ELB limit is reached, the short end of the yield

[19] Experience of developed countries suggests that the floor for nominal interest rates does not have to be zero, as previously assumed (Zero Lower Bound), but remains at a negative level due to, among others, the costs of storing, transferring or spending cash (especially high amounts).

[20] This methodology is discussed in detail in Annex A.2.

curve cannot be shifted and short-term interest rates remain at a constant level. At the same time, long-term rates remain above the level of the ELB and can change freely responding, for example, to non-standard measures undertaken by central banks. Thus, the method proposed by Krippner, using information on interest rate changes for all maturities considered, makes it possible to determine how much the entire yield curve would change in a consistent manner without the ELB constraint. In other words, based on a yield curve estimated with the market data, the so-called "shadow yield curve", i.e. the yield curve where interest rates can assume values that are not limited by the ELB, is determined. On the basis of such an estimated shadow yield curve, consistent rates of all maturities, including the SSR, i.e. the rate with a 3-month maturity, may be derived.

The potential weakness of the above approach lies in the implicit assumption that the mechanism under the impact of long-term interest rates on the economy is similar to that of short-term rates. This is because the above approach assumes that changes in the SSR, resulting from changes in longer-term interest rates, have a very similar impact on the economy as changes in actual short-term rates. Meanwhile, short- and long-term interest rates have a diversified impact on individual groups of economic entities so their macroeconomic effects may differ. This may be particularly relevant in Poland, where bank lending rates are closely linked to short-term rates and the importance of the banking sector as a source of funding is much greater than that of the capital market. Thus, short-term rates have a direct impact on the cost of servicing current liabilities and incurring new liabilities of households and companies, especially small and medium-sized enterprises. In contrast, changes in medium- and long-term interest rates have a direct impact primarily on the cost of debt servicing in the public sector, whereas their impact on private sector financing conditions is more indirect, mainly through their influence on expectations of short-term interest rates as well as on banks' financial performance and corporate bond pricing. On the other hand, expectations of lower interest rates in the future may encourage entities to incur loans with an interest rate linked to the short-term interest rate, with the result that long-term rates may also stimulate growth in lending depending on the level of the short-term rate.

The impact of asset purchases on the exchange rate may differ from the effect of the conventional monetary policy, which results from different roles of short- and long-term rates. In accordance with the theory of uncovered interest rate parity, the expected change in the exchange rate depends on current and expected short-term interest rates in the country and abroad. Changes in long-term interest rates should therefore only affect the exchange rate to the extent resulting from changes in the expected interest rates. This means that asset purchases can only affect the exchange rate through the signalling channel. However, results of empirical studies (Dedola et

al., 2020) indicate that the impact of asset purchases on the exchange rate is also transmitted through adjustments in the risk premium, which only affects long-term interest rates.

To account for potential differences in the impact of short-term interest rates and the bond purchase programme on the exchange rate, the response of the exchange rate to the SOMO programme was estimated using the model of the extended uncovered interest rate disparity proposed by Dedola et al. (2020). The purchase of debt securities leads to a change in the relative assets of central banks, resulting in a change in the exchange rate. In accordance with this approach, expected exchange rate changes can be described as follows:

$$Es_{t+h} - s_{t-1} = \alpha_h \sum_{m=0}^{h} \Delta BS_{t+m} + \omega_{t-1,h} + \varepsilon_{t,h}, \quad (1)$$

where $Es_{t+h} - s_{t-1}$ is the expected change in the exchange rate over the horizon of h periods, ΔBS_{t+m} means the change in the relative assets of central banks between the period $m-1$ and m, $\omega_{t-1,h}$ is a set of control variables while $\varepsilon_{t,h}$ is the error term.

It is possible to identify the effect of quantitative easing basing on the information on the announcements of purchase programmes. In the case of equation (1), standard parameter estimation methods cannot be used due to the endogenous nature of central banks' relative assets. This is, among others, due to the fact that conventional monetary policy will affect ΔBS_{t+m}, thus this variable will not measure solely the impact of the unconventional monetary policy. Therefore, binary variables will be used as instrumental variables, which will assume the value of 1 when quantitative easing programmes are announced and the value of 0 in other cases. Moreover, in line with the empirical strategy proposed by Dedola et al. (2020), a number of control variables $\omega_{t-1,h}$ were used, such as expected values of interest rates, differences between short-term interest rates, differences in Treasury bond yields, the VIX uncertainty index or lags of instrumental variables. In this study the series of euro to Polish zloty exchange rate comes from Bloomberg database and starts from 2008 with monthly frequency. The availability of the above data will enable the empirical analysis only for the euro to Polish zloty exchange rate and it will be assumed that this effect will be analogical for the exchange rates against other currencies.

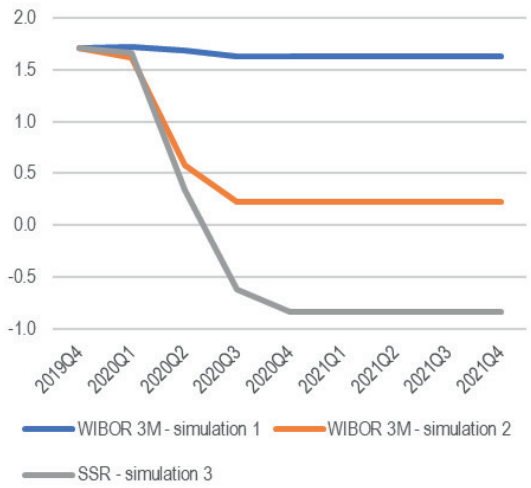
5. Simulation results

This section discusses the results of the counterfactual analysis of the impact of the SOMO on the Polish economy.

5.1 Estimates of the shadow policy rate

Estimates of the shadow policy rate show a significant reduction in the degree of monetary policy restrictiveness since the introduction of the SOMO (Figure 27). Historically, the SSR was at a level similar to the short-term interest rate. However, the asset purchase programme affected the shape of the yield curve by reducing the term premium, which lowered the level of the shadow policy rate. In particular, since June 2020, the SSR remained systematically below the observed interest rate and has assumed negative values. This means that the decline in the degree of monetary policy restrictiveness was much stronger than implied by the level of conventional short-term interest rates.

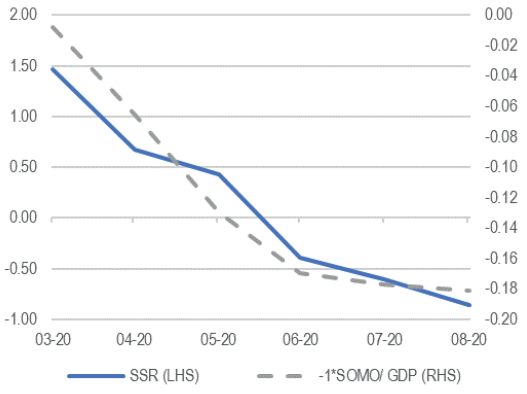
Figure 27 Value of the WIBOR 3M interest rate in the scenarios considered (in %)



Source: own study.

Explanations: simulation 1 – no NBP action, simulation 2 – interest rate cut in 2020, simulation 3 – interest rate cut and introduction of the SOMO.

Figure 28 Estimated shadow policy rate (SSR, in %) and cumulative asset purchases by NBP (SOMO, in % of GDP) between March and August 2020



Source: own study.

The reduction in the degree of monetary policy restrictiveness was linked to asset purchases conducted by NBP. This is illustrated by the negative relationship between cumulative asset purchases and the shadow policy rate (Figure 28).

The estimated scale of the impact of asset purchases on the shadow policy rate in Poland lies within the range of the corresponding estimates of the effects of pre-pandemic asset purchase programmes in the major economies. Indeed, in the United Kingdom, the United States, the euro area and Japan, asset purchases ranging from 3.5% of GDP to 12.5% of GDP were required to reduce the shadow policy rate by 1 percentage point (Wu and Xia 2016, Wu and Xia 2017, Krippner 2020)[21]. Estimates for Poland indicate that the reduction of shadow policy rate by 1 percentage point is due to the asset purchase of 4.5% of GDP. The relatively high effectiveness of asset purchases in Poland may at least partly result from Poland's lower public debt - the scale of asset purchases by NBP is relatively larger in relation to the government bonds supply than in relation to the GDP. Therefore, in order to achieve the same impact on bond yields and the shadow policy rate, necessary asset purchases (as a share of GDP) in Poland may be lower than in the largest economies.

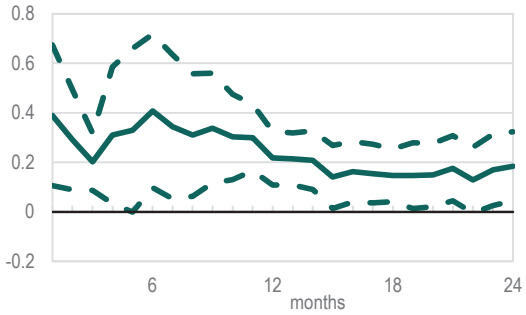
5.2 Estimated impact of the SOMO effect on the currency exchange rate

The purchase of assets by NBP leads to the depreciation of the Polish currency. Estimates of the dynamic response of the Polish zloty against the euro indicate a statistically significant depreciation of the Polish currency in response to the improvement in the ratio of NBP's assets in relation to the ECB's assets. This means that the introduction of the asset purchase programme by one of these central banks leads to the depreciation of the currency associated with that bank. The scale of depreciation of the Polish currency resulting from NBP's unconventional policy is significant here. An asset purchase programme that expands NBP's assets relative to those of the ECB by 1% leads to the depreciation of the Polish zloty against the euro by up to 0.4%, and this effect is achieved within a six-month horizon. Attention should also be paid to the persistence of the depreciation of the Polish zloty in the monetary policy transmission horizon. Although the depreciating effect of the

[21] In the United Kingdom, during the first two QE programmes in 2009-2012: 3.5-4.5% of GDP (Wu and Xia 2017, Krippner 2020); in the euro area in 2014-2018: 4-8% of GDP (Wu and Xia 2017, Krippner 2020); in the United States during the first three QE programmes: 6-8% of GDP (Wu and Xia 2016, Krippner, 2020); in Japan in 2008-2016: 12.5% of GDP (Krippner 2020).

unconventional monetary policy fades over time, it is close to half of the maximum effect over a two-year horizon.

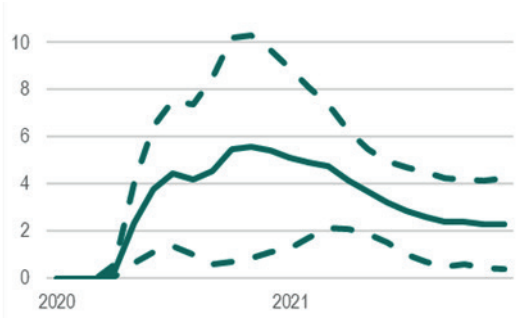
Figure 29 Impulse response function (IRF) estimates of the EUR/PLN exchange rate (an increase means depreciation of the Polish currency) to asset purchases conducted by NBP



Source: own calculations.

Explanations: dashed lines indicate 90% confidence intervals.

Figure 30 Estimates of the SOMO impact on the exchange rate (an increase means the depreciation of the Polish currency)



Source: own calculations.

Explanations: dashed lines indicate 90% confidence intervals.

A hypothetical lack of asset purchases in 2020 would be associated with the stabilisation of the value of the Polish currency. This arises from the fact that the depreciation of the zloty in response to the pandemic shock was moderate and almost the entire scale of this change can be attributed to the estimated SOMO effect. However, it should be kept in mind that the appreciation of the Polish zloty against the euro was affected by the quantitative easing conducted by the ECB, which means that the SOMO programme limited the appreciation effect of the ECB's quantitative easing.

Estimates of the impact of the SOMO on the Polish currency are similar to the effects obtained in studies conducted for developed economies. The results obtained by Dedola et al. (2020) indicate that asset purchases conducted by the FED or the ECB at a level of 1% of GDP reduce the value of the domestic currency by 0.4% and this effect is achieved after 9 months. As in the case of estimates for the zloty-euro exchange rate, the effect of the quantitative easing introduced by the ECB or the FED is inertial for the euro-US dollar exchange rate.

5.3 Analysis of the SOMO effect on the real economy and prices

The introduction of the SOMO programme enabled to reduce the scale of the recession, whereas the impact of the unconventional monetary policy on GDP

growth amounted to 0.1 percentage points in 2020 and 0.5 percentage points in 2021. (Table 1, Figure 31). This is indicated by simulation results from the NECMOD model and the comparison of three scenarios of the monetary policy response to the pandemic shock (see Chapter 4). The positive effect of the unconventional monetary policy is mostly transmitted through two channels. First, easier access to finance, which reflects the decline in the shadow policy rate, leads to an increase in consumer demand and reduces the cost of raising capital, which in turn increases investment in the corporate sector as well as in housing. Second, the impact of the SOMO on the real economy is also transmitted through the trade channel. Owing to the depreciation of the domestic currency, Polish exports become more competitive on foreign markets, which leads to an improvement in the trade balance and an increase in the contribution of net exports to the economic growth.

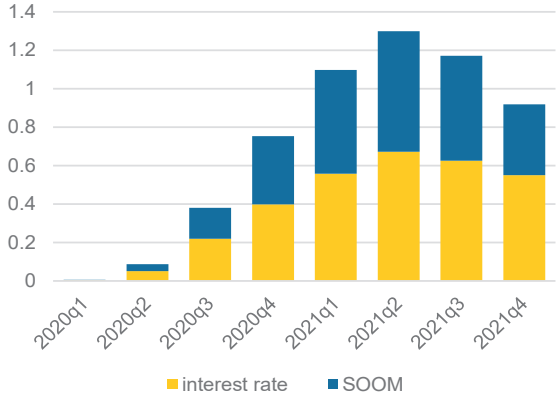
Table 1 Estimated impact of the unconventional and conventional monetary policy of NBP

	SOMO		Interest rate cut		Total	
	2020	2021	2020	2021	2020	2021
WIBOR 3M (p.p.)	-0.5	-1.1	-1.0	-1.4	-1.5	-2.5
CPI inflation (y/y, p.p.)	0.2	0.5	0.1	0.5	0.3	1.0
GDP (y/y, p.p.)	0.1	0.5	0.2	0.6	0.3	1.1
Household consumption (y/y, p.p.)	0.1	0.3	0.2	0.3	0.3	0.6
NEER (%)	3.0	3.4	1.4	4.3	4.4	7.7

Source: NBP study

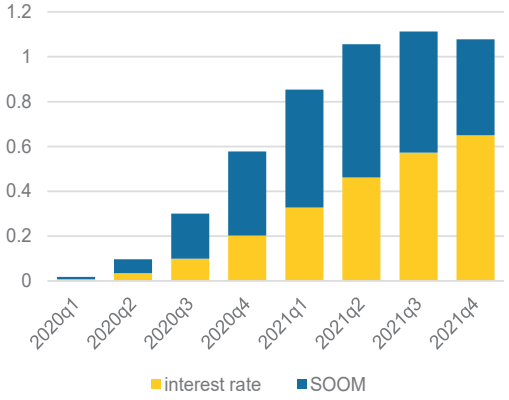
The macroeconomic impact of the SOMO programme is close to the cumulative effect of interest rate cuts in 2020. (Table 1). The results of the NECMOD model simulations indicate that the reference rate cut by 140 points, which took place in the first half of 2020, results in a higher GDP growth rate by 0.2 percentage points in 2020 and 0.6 percentage points in 2021. This means that the total macroeconomic effect of the monetary policy conducted by NBP in the first half of 2020 on GDP growth can be estimated at 0.3 pp. in 2020 and 1.2 pp. in 2021.

Figure 31 Impact of the monetary policy on GDP (y/y growth, deviation from the baseline scenario, in percentage points)



Source: NBP study

Figure 32 Impact of the monetary policy on CPI inflation (y/y growth, deviation from the baseline scenario, in percentage points)



Source: NBP study

The positive effect of the SOMO on GDP is also accompanied by slightly higher consumer price growth due to a somewhat higher increase in prices of imported goods and labour costs. A comparison of the scenarios indicates that CPI growth would be lower in the absence of the use of unconventional monetary policy tools by 0.2 pp in 2020 and 0.5 pp in 2021. As in the case of the economic growth rate, this effect is very close to the impact of interest rate cuts. The detailed results of the NECMOD model simulation suggest that the conventional monetary policy increased the CPI growth rate by 0.1 points in 2020 and 0.5 percentage points in 2021. For both monetary policy easing tools, the growth in consumer prices results from the higher increase in prices of imported goods as well as labour costs. The only difference in this case is the subsequent acceleration of import price growth following the interest rate cut, which results from a more staggered depreciation of the exchange rate.

The presented results are in general close to the estimates of the macroeconomic impact of the SOMO derived from the DSGE model. Kolasa and Wesołowski (2020b) show that the cumulative effect of NBP's monetary policy conducted in the first half of 2020 on GDP growth was about 0.6 and 0.7 percentage points in 2020 and 2021, suggesting that the total effect of the central bank's actions on economic growth in 2020-2021 was similar in both approaches. However, the distribution of the overall impact between conventional and unconventional monetary policy was slightly different. Indeed, the estimates derived from the DSGE model indicate a larger effect of the asset purchase programme compared with the conventional interest rate cut. These differences result from the specification of the models, i.e. the DSGE model

proposed by Kolasa and Wesołowski (2020a), on which the estimates were based, incorporates the propagation of both conventional and unconventional monetary policy across borders to a greater extent thanks to a more detailed representation of international financial markets and capital flows. Moreover, simulations derived from the DSGE model show that the effects of unconventional monetary policy on GDP were slightly faster than in the NECMOD model, which can be explained by more simplified linkages between agents in the domestic economy translating into a quicker amplification of the central bank's actions.

Table 2 Estimated impact of unconventional and conventional monetary policy of NBP on GDP growth (y/y, in pp.) – comparison with the DSGE model

SOMO		Interest rate cut		Total	
2020	2021	2020	2021	2020	2021
0.1	0.5	0.2	0.6	0.3	1.1
DSGE (Kolasa and Wesołowski, 2020b)					
0.5	0.6	0.2	0.3	0.6	0.7

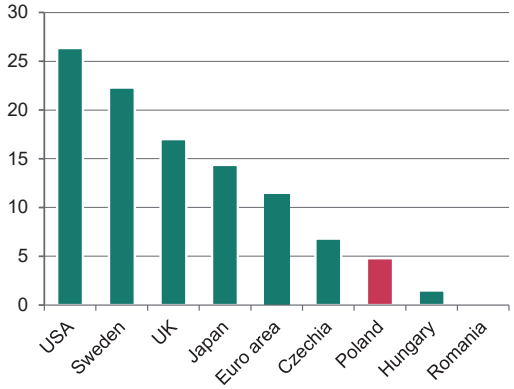
Source: NBP study

5.4 Discussion of the results

The estimated scale of the macroeconomic effect of asset purchases by NBP is lower than the corresponding estimates if the effectiveness of unconventional monetary policy in the United States and the United Kingdom and close to the results for the euro area. The estimates discussed in the previous chapter imply that a 1% purchase of NBP's assets is associated with the maximum effect on GDP and consumer price growth of 0.13 percentage points. Irrespective of the methodological differences, this scale is very close to the estimates obtained for the euro area, where the introduction of an easing programme of 1% of GDP increases the maximum GDP growth by approx. 0.14 percentage points (Sahuc, 2016) – 0.16 percentage points (Andrade et al., 2016) and inflation by approx. 0.06 percentage points (Andeade et al., 2016) – 0.1 percentage points (Sahuc, 2016). On the other hand, for the United States and the United Kingdom, the estimates of the maximum effect are much higher, ranging from 0.2 percentage points (Hesse et al., 2018) to 0.62 percentage points for GDP growth (Weale and Wieladek, 2016). In addition, the UK and US economies demonstrate a higher sensitivity of consumer prices to quantitative easing, while the estimates of the maximum effect can be narrowed down in the range from 0.2 percentage points. (Hesse et al., 2018) to 0.32 percentage points (Weale and Wieladek, 2016).

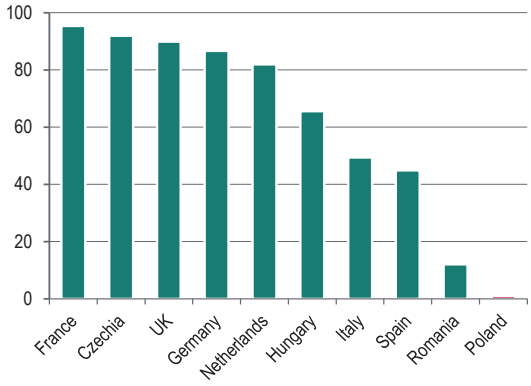
The relatively smaller macroeconomic impact of asset purchases by NBP is associated with the relatively lower strength of the interest rate channel in the monetary policy transmission mechanism in Poland. This results from the structural factors which, as the empirical studies show, are also characteristic for other Central and Eastern European countries (Georgiadis, 2014). The main factors weakening the strength of the response of the Polish economy to changes in the domestic monetary policy include a lower level of development of the financial system and a less importance of bank lending as a source of financing investment. The weaker effect of asset purchases on the Polish economy is also influenced by the lower importance of long-term interest rates in the Polish financial system. In particular, the size of the corporate debt securities market (Figure 33) and the share of fixed-rate mortgages in the mortgage market (Figure 34) are significantly smaller than in developed economies. On the other hand, in the case of Poland, the exchange rate channel is still quite important, while in developed countries its role is limited due to the greater participation of companies in the global supply and production chains.

Figure 33 Debt of non-financial corporations in the form of long-term debt instruments (% of GDP)



Source: Eurostat.

Figure 34 Share of fixed-rate mortgages in the mortgage market (in %)



Source: ECB.

The lower importance of long-term interest rates in the Polish economy may even reduce the estimated macroeconomic effect of asset purchases. As mentioned, the role of corporate bonds in external financing of enterprises or the share of loans with a fixed interest rate is much lower in Poland than in developed economies. Therefore, the assumption that the impact of the SSR on economic activity is similar to the impact of the short-term interest rate (except for the exchange rate channel) is of key importance for the analysis performed. This assumption implies that a decline in long-term interest rates resulting from asset purchases boosts economic activity in the same way as the reduction in short-term interest rates. However, if it is not fulfilled, namely, the impact of long-term interest rates on the economic activity is weaker, the effectiveness of asset purchases may be lower.

However, estimates of the macroeconomic impact of the unconventional monetary policy should be interpreted in terms of a lower bound on this effect due to the omission synergies between fiscal and monetary policy. As mentioned in section 2.3, the loosening of fiscal policy in response to the pandemic shock comprised a number of anti-crisis measures. Additional simulations of the NECMOD model allow to assess that the fiscal policy instruments used increased the GDP growth rate by 2.1 and 1.3 percentage points in 2020 and 2021, respectively, while their impact on CPI inflation is estimated at -0.1 percentage points in 2020 and 1.1 percentage points in 2021. However, this effect would probably be smaller in the absence of asset purchases by NBP, which results from the positive impact of accommodative monetary policy on fiscal multipliers (IMF, 2020b). Moreover, the very nature of the unconventional monetary policy allowed to maintain the liquidity in the Treasury bond market which, in turn, has enabled safe financing of the anti-crisis package. A final rationale in favour of a larger real effect of asset purchases is related to the fact that the empirical strategy used to identify the impact of the SOMO on the key variables may not reflect the aggregate impact transmitted through the signalling channel. An indirect empirical argument here is, for example, the study by Hesse et al (2018), who show that the highest effect of quantitative easing programmes was achieved for the first unconventional measures of the FED or the Bank of England. This may reflect the considerable role of the impact of asset purchases on the expectations of enterprises or households regarding the improvement of the economic situation at the time the first asset purchase programme was launched. In the context of this study, the overall impact on the expectations of economic agents is difficult to measure merely on the basis of the response of financial variables.

Conclusion

The paper presents the macroeconomic effect of structural open market operations launched by NBP in response to the global pandemic shock. The estimates presented allow to conclude that asset purchases by the central bank reduced the extent of the recession in the Polish economy in 2020 to a similar extent as interest rate cuts. In a hypothetical situation where NBP failed to launch the SOMO, GDP growth would be lower by 0.1 pp. in 2020 and 0.5 pp. in 2021. This effect resulted from the improvement in financing conditions, which supported consumer and investment demand and the depreciating nature of the SOMO, which stimulated Polish exports by improving price competitiveness. The SOMO also affected, through the higher price growth of imported goods and labour costs, higher price growth – this effect is estimated around 0.2 percentage points in 2020 and 0.5 percentage points in 2021. In needs to be stressed out that the effect on prices should be interpreted jointly with the effect on GDP. Higher inflation rate is a consequence of a shallower recession in 2020 and a faster recovery in 2021 as compared to the alternative scenario without the implementation of SOMO.

The macroeconomic effect estimates presented are similar to those for the euro area and around 2-3 times lower than those for the United States and the United Kingdom. The lower impact of asset purchases in this case can be explained by the lower level of financial system development, the lower level of public and private debt or the lesser importance of bank credit as a source of investment financing, i.e. structural conditions that weaken the strength of the interest rate channel. Moreover, discrepancies in the estimates may be affected by methodological differences. Due to the lack of historical data on asset purchases before the pandemic shock, the estimates for the macroeconomic effect of the SOMO are based on an *ex-ante* analysis, while the estimates available in the literature usually result from an *ex-post* analysis.

The actual effect of the SOMO may even be slightly smaller than estimated due to the lower importance of long-term interest rates in the Polish financial system compared to developed economies, as manifested by the low importance of corporate bonds as a source of corporate financing and the very limited share of fixed interest rate loans in the stock of loans, especially mortgage loans. Estimates of the SOMO effect assume that the impact of changes in the shadow policy rate on economic activity is analogical to the impact of the "standard" short-term rate, i.e. they somehow assume that the changes in long-term rates affected by asset purchases have a similar impact on the economy as the changes in short-term rates.

On the other hand, however, there are many indications that the actual impact of the SOMO on the macroeconomic variables may be higher than estimated. This may result, for example, from the synergy of the unconventional monetary policy with

the fiscal policy. The launch of anti-crisis programmes was associated with an increase in indebtedness, while it was owing to the introduction of the SOMO by NBP that it was possible to keep the cost of borrowing at a relatively low level. Another argument supporting the higher effectiveness of the asset purchase programme in the Polish economy is the potentially non-linear nature of the impact. Although the analysis uses a multi-equation NECMOD model incorporating a range of economic mechanisms, it cannot be excluded that the SOMO effect is significantly higher due to the unprecedented scale of the recession in 2020 Q2. The final argument is that the methodology adopted does not allow for measuring the cumulative effect of the SOMO transmitted through the signalling channel and, in particular, does not enable taking into account the effect of an improvement in economic agents' expectations.

A natural extension of the analysis is an attempt to assess the macroeconomic effect of the SOMO programme on an *ex-post* basis. However, at the moment, an *ex-post* assessment of the macroeconomic effect of the asset purchase programme conducted by NBP seems impossible due to (i) the lack of historical data on previous asset purchase programmes conducted by the central bank in Poland, (ii) the lack of a definitive termination of the SOMO programme, and (iii) the presence of staggered effects of changes in monetary policy restrictiveness. This kind of analysis will therefore be possible only in several years' time.

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Annex A.1 Review of empirical studies on the macroeconomic effects of quantitative easing programmes

Table 3 Estimates of quantitative easing effects on GDP and inflation

Study	Method	Transmission channel[1]	GDP[2]	Inflation[3]	Comments
United States					
Chung et al. (2012)	FRB/US model	portfolio	3.0%	1.0 pp	3 phases of asset purchases by the Fed.
Chen et al. (2012)	DSGE, counterfactual analysis		0.13 pp	0.03 pp	LSAP II.
Baumeister and Benati (2013)	TVP-SVAR	portfolio, uncertainty reduction	0.9 pp	0.5 pp	No reduction in yield spreads of 60 basis points.
Gertler and Karadi (2013)	DSGE, counterfactual analysis		3.50%	4.0 pp	QE1.
Engen et al. (2015)	FRB/US model	signalling and portfolio channels		0.5 pp	Estimate of changes in expectations regarding the monetary policy rule and the impact of asset purchases on term premiums.
Weale and Wieladek (2016)	BVAR	portfolio and uncertainty reduction channels	0.58%	0.62%	LSAP effect of 1% GDP. Low efficiency of the signalling channel.
Hesse et al. (2018)	BVAR		0.10%	0.10%	Average effect associated with asset purchases leading to a decline in the term premium of 10 basis points.
	BVAR		0.18%	0.12%	LSAP3 effect, taking into account market expectations.
United Kingdom					
Kapetanios et al. (2012)	BVAR, MS-SVAR, TVP-SVAR	reduction of uncertainty	1.50%	1.25 pp	Effect of bond yield spreads falling by 100 basis points following QE1.
Baumeister and Benati (2013)	TVP-SVAR	portfolio, uncertainty reduction	2.0 pp	2.0 pp	No reduction in yield spreads of 50 basis points.
Pesaran and Smith (2016)	ARDL		0.75- 1.0 pp		Effect of bond yield spreads falling by 100 basis points.
Weale and Wieladek (2016)	BVAR	uncertainty reduction, signalling	0.25%	0.32 pp	LSAP effect of 1% GDP. Portfolio channel inefficiency.

Neuenkirch (2020)	treatment effect analysis		0.6- 0.7 pp	0.77- 0.99 pp	
Study	**Method**	**Transmission channel[1]**	**GDP[2]**	**Inflation[3]**	**Comments**
Euro area					
Altavilla et al. (2016)	regression, BVAR	signalling	heterogeneous effect[4]: ES: 2.01 (0.80) IT: 1.50 (0.81) FR: 0.46 (0.64) DE: 0.34 (0.60)	heterogeneous effect[4]: ES: 0.74 (0.65) IT: 1.21 (0.86) FR: 0.28 (0.68) DE: 0.28 (0.67)	Response of the yields to information related to the OMT programme.
Andrade et al. (2016)	DSGE and time series analysis		1.10%	0.40 pp	APP effect.
Sahuc (2016)	DSGE	portfolio and signalling	0.90 pp	0.60 pp	APP effect, dominant signalling channel.
Cova et al. (2019)	DSGE	portfolio and liquidity	1.40%	0.80 pp	APP effect.
Mouabbi and Sahuc (2019)	DSGE		1.10 pp	0.70 pp	Effect of unconventional policy in the period 2014Q1-2017Q2.
Hohberger et al. (2019)	DSGE		0.30%	0.50 pp	Maximum contribution to GDP growth and CPI inflation of 0.6 pp in 2016.
Japan					
Schenkelberg and Watzka (2013)	SVAR		0.40% (cf. notes)	minor, temporary	QE shock: BoJ reserves increase by 7%. Industrial production grows by 0.4% after about 2 years.
Hausman and Wieland (2015)	VAR, counterfactual analysis	signalling	1.00 pp		The effect is measured as the contribution of QQE to growth in 2013.

Notes: LSAP - large-scale asset purchase.
[1] Where a quantitative easing channel can be identified.
[2] % for the GDP level and the percentage point for the GDP growth rate.
[3] % for the price level and a percentage point for the inflation rate.
[4] The estimated probability of a positive effect is shown in brackets. The estimated effects are expressed in standard deviations for the variables over a three-year horizon.

Source: own elaboration.

Table 4 Estimates of quantitative easing effects on the exchange rate and retail credit

Study	Method	Transmission channel[1]	Country/sample	Effect	Comments
Real exchange rate					
Dedola et al. (2020)	local projection	portfolio	US/EA	-7%	An increase of about 20% in the relative size of central banks' balance sheets. Impact measured by generalised UIP condition.
Nominal exchange rate					
Georgiadis and Gräb (2016)	event study	signalling	EA	cumulative depreciation of the euro: 6.4% (effective) 8.4% (USD/EUR) 7.7% (JPY/EUR)	Response to information related to the ECB APP programme.
Neely (2015)	event study	portfolio	US	cumulative depreciation of the US dollar: 5.73 (AUD/USD) 6.16 (CAD/USD) 7.76 (EUR/USD) 6.70 (JPY/USD) 3.54 (GBP/USD)	Evaluation of LSAP effects.
retail credit (the sum of the credit to households and non-financial corporations)					
Altavilla et al. (2016)	event study, BVAR	signalling	EA	heterogeneous effect[2]: ES: 2.31 (0.75) IT: 3.58 (0.82) FR: 1.38 (0.22) DE: 1.08 (0.90)	Response of the yields to information related to the OMT programme.

Notes:
[1] Where a quantitative easing channel can be identified.
[2] The estimated probability of a positive effect is shown in brackets. The estimated effects are expressed in standard deviations for the variables over a three-year horizon.

Source: own elaboration.

Annex A.2 Methodology of the shadow policy rate estimation

The annex below describes in detail the methodology used for estimating the short-term shadow policy rate proposed by Krippner (2015).

A.2.1 Term structure model K-ANSM (2)

The Krippner approach assumes that the yield curve for the shadow[22] interest rates at a given point in time and its evolution over time can be described by a certain class of term structure models assuming no arbitrage (Arbitrage free Nelson-Siegel models, ANSMs). Then, at moment t the short-term shadow interest rate r_t is an affine function of the n unobservable variables (factors) described by the vector x_t. Under physical measure the x_t dynamics is described by the Ornstein-Uhlenbeck (vector) process[23]:

$$dx_t = \kappa(\theta - x_t)dt + \sigma dW_t, \tag{2}$$

where θ is the vector of constants representing the long-term mean level of the process x_t, κ is the parameter matrix defining the rate of return to the mean value θ, σ is the variance-covariance matrix of random disturbances for x_t and W_t is the Wiener process. The x_t dynamics for the risk-neutral measure[24] are also described by the Ornstein-Uhlenbeck process (with different, transformed parameter values):

$$dx_t = \tilde{\kappa}\left(\tilde{\theta} - x_t\right)dt + \sigma d\widetilde{W}_t. \tag{3}$$

In this study, the K-ANSM (2) term structure model with two components was used to estimate the shadow yield curve: (i) $L(t)$ - *Level*, and (ii) $S(t)$ - *Slope*. Furthermore, due to the identification problem, it is not possible to estimate all parameters simultaneously in the general form of the K-ANSM (2) model. As a consequence, some parameters have to be assumed (calibrated) *a priori*. One of the popular

[22] This is a hypothetical yield curve that would exist in the absence of cash, i.e. in a situation where the investor has no opportunity to switch from a financial instrument to cash.

[23] The Ornstein-Uhlenbeck stochastic process, described by the differential equation (2), can be treated as a modification of the random walk process with continuous time. The Ornstein-Uhlenbeck process is characterised by the property of reverting to the mean (in other words, over time it tends to drift towards its mean function), whereas the speed of this convergence is greater, the further the values of the process deviate from the mean.

[24] A risk-neutral measure is often used in the valuation of financial instruments. In general, relative to this measure, the value of a financial instrument is equal to the expected value of the discounted payment associated with that instrument. The physical (actual) measure, on the other hand, illustrates the actual distributions of probability that participants in financial markets have. Consequently, the process describing the x_t dynamics in physical measure must be adjusted by the risk premium, so that it can represent the observable term structure.

approaches is to impose restrictions which are standard in the literature, for example assuming that $\tilde{\theta} = 0$, or assuming that the matrix σ is lower triangular, cf. Krippner 2015).

Then, in the K-ANSM (2) model, the short-term shadow rate r_t at moment t is provided by the formula:

$$r_t = L(t) + S(t), \tag{4}$$

where

$$x_t = \begin{pmatrix} L(t) \\ S(t) \end{pmatrix}, \kappa = \begin{bmatrix} \kappa_{11} & \kappa_{12} \\ \kappa_{21} & \kappa_{22} \end{bmatrix}, \theta = \begin{pmatrix} \theta_1 \\ \theta_2 \end{pmatrix}, \sigma = \begin{bmatrix} \sigma_1 & 0 \\ \varrho_{12} * \sigma_2 & \sqrt{1 - \varrho_{12}{}^2} \end{bmatrix},$$
$$\tilde{\kappa} = \begin{bmatrix} 0 & 0 \\ 0 & \emptyset \end{bmatrix}, \tilde{\theta} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}. \tag{5}$$

Under the above assumptions, the instantaneous shadow forward rate can be described by the function $f(t, \tau)$:

$$f(t,\tau) = L(t) + S(t) * \exp(-\phi\tau) - \sigma_1{}^2 * \frac{1}{2}\tau^2 - \sigma_2{}^2 * \frac{1}{2}[G(\phi,\tau)]^2 - \varrho_{12}\sigma_1\sigma_2 * \tau G(\phi,\tau) \tag{6}$$

where τ means the (future) time horizon from moment t and

$$G(\phi,\tau) = \frac{1}{\phi}\big(1 - exp(-\phi\tau)\big), \tag{7}$$

Shadow interest rates[25] are determined using shadow forward rates (6) based on the standard relationship in yield curve models:

$$R(t,\tau) = \frac{1}{\tau}\int_0^\tau f(t,u)\,du. \tag{8}$$

In the Krippner approach, the Effective Lower Bound mechanism was imposed as proposed by Black (Krippner 2015):

$$\underline{r_t} = max(r_l, r_t), \tag{9}$$

i.e. the short-term (observed) interest rate $\underline{r_t}$ is equal to the maximum of the (unobservable) short-term shadow rate r_t and the effective lower bound r_l. Alternatively, (9) can be written as follows:

$$\underline{r_t} = r_t + max(r_l - r_t, 0), \tag{10}$$

which means that the nominal short-term rate can be represented as the sum of the short-term shadow rate r_t and the component measuring the payoff for an instantaneous call option on the short-term shadow rate - $max(r_l - r_t, 0)$, which is hereinafter referred to as the "option effect". As a consequence, using (10), it can be shown that in the K-ANSM (2) model, where a lower bound on nominal rates exists,

[25]These are therefore interest rates that would be observed in the absence of the lower bound.

the forward rate $\underline{f}(t,\tau)$ can be represented as the sum of the instantaneous forward shadow rate $f(t,\tau)$ (6) and the $z(t,\tau)$ factor stemming from the option effect:

$$\underline{f}(t,\tau) = f(t,\tau) + z(t,\tau). \tag{11}$$

In the K-ANSM (2) model, the $z(t,\tau)$ component is provided by the formula:

$$z(t,\tau) = [f(t,\tau) - r_L] * \left(1 - \Phi\left[\frac{f(t,\tau) - r_L}{\omega(\tau)}\right]\right) + \omega(\tau) * \phi\left[\frac{f(t,\tau)\,(\tau) - r_L}{\omega(\tau)}\right], \tag{12}$$

where:

$\Phi(\cdot)$ is the cumulative standard normal density function and $\phi(\cdot)$ denotes the standard normal probability density function, and $\omega(\tau)$ is provided by the formula:

$$\omega(\tau) = \sqrt{{\sigma_1}^2\tau + {\sigma_2}^2 G(2\phi,\tau) + 2\varrho_{12}\sigma_1\sigma_2 G(\phi,\tau)}. \tag{13}$$

As a result, taking into account (6), (11), (12) the instantaneous forward interest rate subject to the lower bound is expressed by the formula:

$$\underline{f}(t,\tau) = r_L + (f(t,\tau) - r_L) * \Phi\left(\frac{f(t,\tau) - r_L}{\omega(\tau)}\right) + \omega(\tau) * \phi\left(\frac{f(t,\tau) - r_L}{\omega(\tau)}\right). \tag{14}$$

Zero-coupon interest rates calculated from the K-ANSM (2) model (hereafter LB interest rates) are obtained, analogously to shadow rates, from the equation:

$$\underline{R}(t,\tau) = \frac{1}{\tau}\int_0^\tau \underline{f}(t,\tau)\,du. \tag{15}$$

A.2.2 Estimation strategy of the K-ANSM (2) model parameters

The K-ANSM (2) model presented in the previous section, assuming the exogenous nature of r_L, requires the estimation of a set of 10 parameters:

$$\boldsymbol{B} = \{\phi, \theta_1, \theta_2, \kappa_{11}, \kappa_{12}, \kappa_{21}, \kappa_{22}, \sigma_1, \sigma_2, \varrho_{12}\} \tag{16}$$

derived from the definition of the assumed stochastic process for the short-term rate (cf. 2 and 5) and the σ_η parameter from the Kalman filter measurement equation.

The strategy proposed by Krippner (Krippner 2015) for estimation of the K-ANSM (2) model parameters is based on the maximum likelihood method and the application of the appropriate Kalman filter to determine the state variables based on these parameters. Generally speaking, in each iteration of the optimisation algorithm, a set of key parameters and estimates of the state variables are updated. This process is repeated until a certain level of convergence is reached, which in the study under analysis involves changing the value of the log-likelihood function not exceeding the tolerance range for this optimisation algorithm.

In particular, for a certain sample of size T, the following form of the log-likelihood function is maximised:

$$log_{lik(\boldsymbol{B},\sigma_\eta,R_1,\dots,R_T)} = -\frac{1}{2}\sum_{t=1}^{T}[K * \log(2\pi) + log|M_t| + \eta_t{}' M_t{}^{-1}\eta_t], \quad (17)$$

where $t = 1,2,..T$ and $R_t = [R_t(\tau_1), \dots, R_t(\tau_K)]$ are the observed zero-coupon interest rates at moment t for available K maturities, $\tau_1, \dots, \tau_1$,. η_t are the estimates of the random component unexplained by the yield curve model at moment t, while M_t are the quantities obtained at each step $t = 1,2,..T$ from the Kalman filter. In particular, in each iteration of the algorithm, for the given values of the parameter set, state variables (L(t) and S(t)) are generated using the Kalman filter for $t = 1,2,..T$ and the quantities η_t and M_t are estimated. The latter are then used to calculate the value of the log-likelihood function (17) for the set of parameters from a given iteration.

The state equation is based on a discretisation of the solution of the stochastic differential equation (2) for a certain time step Δt, which depends on the frequency of observation. In general, the equations for $L(t)$ and $S(t)$ take the form of the first order vector autoregression model:

$$x_t = \theta + exp(-\kappa\Delta t)(x_{t-1} - \theta) + \varepsilon_t, \quad (18)$$

where the ε_t variance is provided by the formula:

$$var(\varepsilon_t) = \int_0^{\Delta t} \exp(-\kappa u)\sigma\sigma')\exp(-\kappa' u)du, \quad (19)$$

The measurement equation, on the other hand, is expressed by the formula:

$$\begin{bmatrix} R_t(\tau_1) \\ \vdots \\ R_t(\tau_K) \end{bmatrix} = \begin{bmatrix} \underline{R_t}\,(x_t, \tau_1, \boldsymbol{B}) \\ \vdots \\ \underline{R_t}\,(x_t, \tau_K, \boldsymbol{B}) \end{bmatrix} + \begin{bmatrix} \eta_t(\tau_1) \\ \vdots \\ \eta_t(\tau_K) \end{bmatrix}, \quad (20)$$

where $\underline{R_t}\,(x_t, \tau_K, \boldsymbol{B})$ are the LB interest rates, $\eta_t(\tau_1)$ is the stochastic component in the K-ANSM (2) model.

The study also uses the assumption stipulating that the covariance variance matrix for η_t is homoscedastic and therefore characterised by the constant variance over time

$$\Omega_\eta = \text{diag}[\sigma_\eta^2, \dots, \sigma_\eta^2]. \quad (21)$$

Furthermore, it is assumed that the stochastic components ε_t and η_t are not correlated over time and the covariances between ε_t and η_t are zero. Due to the non-linearity of $\underline{R}\,(t, \tau)$ with respect to the state variables, Krippner uses the iterated extended Kalman filter (IEKF) to estimate them.

In conclusion, the estimation method results in the simultaneous estimation of the set of parameters $\{\phi, \theta_1, \theta_2, \kappa_{11}, \kappa_{12}, \kappa_{21}, \kappa_{22}, \sigma_1, \sigma_2, \varrho_{12}, \}$ and the time series of $L(t)$ and $S(t)$ factors allowing for the estimation of the short-term shadow rate for $t = 1,2,..T$.

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