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Monetary policy and its transmission in a globalised world

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Abstract

This paper estimates and compares the international transmission of European Central Bank (ECB) and Federal Reserve System monetary policy in a unified and methodologically consistent framework. It identifies pure monetary policy shocks by purging them of the bias stemming from contemporaneous central bank information effects. The results suggest that there is a hierarchy in the global spillovers from ECB and Federal Reserve monetary policy: while the spillovers to consumer prices are relatively small in both directions, Federal Reserve monetary policy shocks have a larger impact on euro area financial markets and real activity. Federal Reserve monetary policy also has a significantly larger impact than ECB monetary policy on real and financial variables in the rest of the world.

Non-technical summary

For the last three decades global trade and financial links have both strengthened considerably. Similarly, the global co-movement of macroeconomic variables such as inflation and GDP growth as well as financial variables such as equity prices has increased. These developments – often referred to as "globalisation" – suggest a tighter interdependence across economies.

This raises a set of important questions for central banks in systemic economies, such as the European Central Bank (ECB) or the US Federal Reserve System. For example, to what extent do monetary policy actions in one jurisdiction spill over to real and financial variables across the Atlantic? What are the underlying transmission channels? Do the ECB and the Federal Reserve retain control over domestic inflation in the presence of these spillovers? Going beyond bilateral spillovers between the United States and the euro area, a second set of questions relates to the impact of ECB and Federal Reserve monetary policy on global financial markets and emerging economies. For example, can monetary policy spillovers account for the high degree of cross-country co-movement in real and financial variables? Can central banks in emerging economies retain control over inflation and real activity in the presence of monetary policy spillovers from systemic advanced economies? How do these issues speak to the question of whether there is a case for international monetary policy coordination?

Because these questions all relate to the effects of monetary policy, answering them requires a careful separation of monetary policy from other contemporaneous effects, in particular central bank information shocks. Such shocks from the ECB and the Federal Reserve have recently been shown to play an important role in driving the business cycle. We adopt a state-of-the-art identification approach to disentangling exogenous variation in monetary policy from systematic responses to economic developments. The approach is particularly helpful in distinguishing such exogenous monetary policy shocks from central bank information shocks. In the latter, a central bank announcement is interpreted by financial markets as revealing private information of the central bank, independently of a possible change in the central bank's monetary policy stance. On the basis of this identification approach, the discussion paper compares ECB and Federal Reserve monetary policy spillovers – both to each other's economy and to other economies such as emerging markets – within a unified and consistent framework. Such comparisons are difficult on the basis of existing contributions, because the latter differ widely in terms of the estimation methodology applied, the identification approach, and sample periods.

We find that both the ECB and the Federal Reserve retain control over domestic variables, especially inflation, irrespective of the cross-border impact of monetary policy. In particular, instances of monetary policy tightening by either the ECB or the Federal Reserve raise domestic bond yields, depress domestic equity markets, slow inflation and output growth, and are followed by an appreciation of the respective currency. Compared with the domestic effect, the spillover effects of monetary policy between the euro area and the United States on output and inflation are small, despite notable spillovers from Federal Reserve monetary policy to euro area financial markets. Although we find that contractionary monetary

policy shocks in the United States *raise* euro area inflation temporarily, probably through the impact of a euro depreciation on import and commodity prices, the effect is too short-lived to qualify as a trade-off for monetary policy. On the basis of these results there appears to be no need for transatlantic monetary policy coordination in normal times.

The paper also evaluates the size of ECB and Federal Reserve monetary policy spillovers to the rest of the world, focusing especially on emerging economies and commodity prices. In this context, and consistent with the dominance of the US dollar in the international monetary system, our results show the presence of a "hierarchy" of spillovers. Specifically, the monetary policy of the Federal Reserve, but not of the ECB, has large spillover effects on global financial markets. The impact is even stronger on the financial markets of emerging economies, resulting in a large effect on their economic activity. In contrast, ECB monetary policy shocks appear to operate mainly via trade, resulting in a much smaller impact on the real activity of emerging economies but still significantly influencing commodity prices, in particular when oil is excluded. Local monetary policy in emerging economies does not seem to offset spillovers from either ECB or Federal Reserve policy shocks.

Unlike the manageable bilateral spillovers between the euro area and the United States, the spillovers to the rest of the world suggest that both ECB and Federal Reserve monetary policy actions may imply policy trade-offs elsewhere, in particular in emerging economies. Although our findings suggest that there could in theory be gains from international monetary policy coordination between major advanced and emerging economies, practical obstacles undermine the case for coordination.

1. Introduction

Understanding how globalisation affects the monetary transmission mechanism is vital for central banks. Over the past few decades, the exchange of goods, services, technology, capital and information across national borders has intensified rapidly. As a consequence, individual economies have become increasingly integrated with the rest of the world. Trade and financial globalisation change the dynamic interdependencies of economies, for example by increasing their exposure to foreign shocks while facilitating international risk sharing. Because these changes also affect the transmission of monetary policy, understanding the implications of globalisation is crucial for central banks.

The global financial crisis and recourse to unconventional monetary policy measures have created renewed interest in the international dimension of national monetary policy. At the turn of the century, Obstfeld and Rogoff (2002) argued in an influential paper that even in a completely integrated world, cross-border spillovers and externalities from national monetary policies were likely to be small and thus international coordination dispensable. National monetary policies were therefore right to focus on purely domestic objectives. Under this pre-crisis view, national monetary policy that was optimal from a purely domestic perspective would be (almost) optimal from a global perspective, at least under normal circumstances.[1] Events since then, however, have highlighted the potential for shocks to propagate across borders and rekindled the debate on international monetary policy coordination.[2] In particular, these events exposed the central role of financial linkages in the propagation and amplification of spillovers across borders, and revealed international side effects of new policy instruments. They also induced policy coordination among central banks in several instances.

Against the background of this experience, we revisit in this paper the transmission of monetary policy across borders in today's globalised world. We examine the size of monetary policy spillovers and their transmission channels, as well as their implications for the effectiveness and the desirability of international coordination. The analysis focuses on spillovers from monetary policy between the two largest currency areas with developed financial markets, namely the United States and the euro area, exploring the role of spillovers for domestic monetary policy effectiveness and autonomy. It then examines spillovers from Federal Reserve and ECB monetary policy to the rest of the world, in particular to emerging economies.[3]

More specifically, we explore the domestic effectiveness of the ECB's and the Federal Reserve's monetary policy as well as the size of their transatlantic spillovers. To do so, we identify exogenous changes in ECB and Federal Reserve monetary policy and estimate their impact on the domestic economy as well as across the Atlantic, in particular on financial markets, inflation and real activity. We employ the identification approach recently proposed by Jarociński and Karadi (2020), which rests on the assumption that a contractionary monetary policy shock is characterised by a surprise increase in

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[1] "Normal circumstances" refers in particular to the absence of financial instability.
[2] See Draghi (2016).
[3] The academic and policy literature on this topic is too vast to summarise here. We discuss the main contributions in Section 4.

domestic sovereign bond yields and a surprise fall in equity prices in a short time window around a monetary policy announcement. As Jarociński and Karadi indicate, the appealing feature of this identification approach is that it distinguishes a contractionary monetary policy shock from a positive central bank information shock. In particular, while both feature a rise in domestic sovereign bond yields, only a positive information shock is accompanied by a rise in equity prices. Such a positive information shock occurs if markets interpret a contractionary monetary policy announcement as the central bank responding to a better-than-expected economic outlook – and hence as good news about the economy. Importantly, Jarociński and Karadi (2020) document that it is crucial to account for central bank information shocks in order to consistently estimate the effects of monetary policy shocks.

The main contribution of this discussion paper is a comparison of ECB and Federal Reserve monetary policy spillovers – both bilaterally and to the rest of the world – within a unified and consistent framework. Such comparisons are difficult to make on the basis of the existing literature, because the analyses differ widely in terms of the estimation methodology applied, the identification approach and sample periods.

We first show that both the ECB and the Federal Reserve have an impact on domestic financial conditions and inflation even in a highly globalised world. Surprise monetary policy tightening by either the ECB or the Federal Reserve raises domestic sovereign and corporate bond yields, depresses domestic equity markets, slows inflation and real activity, and is followed by an appreciation of the domestic currency.

Our second key finding is that there is a "hierarchy" of monetary policy spillovers, with those stemming from the Federal Reserve, especially spillovers to financial markets, being larger than those from the ECB. Spillovers from ECB monetary policy to the United States are small and also imprecisely estimated, while spillovers from Federal Reserve monetary policy strongly affect euro area financial markets (in particular corporate bond prices). We also find some spillovers from Federal Reserve monetary policy to euro area real activity and prices, but the spillovers to inflation, especially, are very short-lived. These findings are consistent with both the Federal Reserve and the ECB being able to achieve their mandates even in a highly globalised world and in the presence of monetary policy spillovers.

Our findings also imply that neither ECB nor Federal Reserve monetary policy spillovers pose significant trade-offs for monetary policy on the other side of the Atlantic. Such trade-offs would manifest themselves in significant and at least somewhat persistent spillovers to variables such as inflation and real activity. The lack of evidence of transatlantic externalities originating from ECB and Federal Reserve monetary policy[4] highlight that there is no need for coordinating monetary policies, at

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[4] The effect of a surprise US monetary policy contraction on euro area inflation is too short-lived to be qualified as a true monetary policy externality, as the ECB would not react to changes in inflation that do not impinge on medium-term price stability.

least under normal circumstances. Our findings are at the same time not inconsistent with the instances of explicit monetary policy coordination during the global financial crisis. The coordinated interest rate cut in October 2008, for example, can be interpreted as a reaction to a common shock (the global financial crisis) with the main objective being to maximise market impact. Such coordination in times of crisis is therefore primarily a useful communication device for reducing uncertainty in extraordinary times (see Coenen et al., 2017) rather than a classic coordination arrangement under which central banks internalise cross-border externalities from monetary policy action.

Finally, we find significant spillovers from in particular Federal Reserve monetary policy shocks to emerging economies. Consistent with the dominance of the US dollar in the international monetary system, our results suggest that there is also a "hierarchy" of spillovers in this case. Federal Reserve monetary policy shocks, in particular, result in large spillovers to financial conditions and real activity in emerging economies. Spillovers from ECB monetary policy, by contrast, are largely confined to trade (and, perhaps surprisingly, commodity prices). In contrast to the bilateral spillovers between the euro area and the United States, our findings suggest that ECB and Federal Reserve monetary policy actions may imply policy trade-offs in emerging economies. While we do not explore the root causes for these trade-offs, we infer that these could be related to greater frictions in emerging economies and limitations in their policy toolkits. This suggests that there may be gains from international monetary policy coordination between major advanced and emerging economies, but practical obstacles undermine the case for coordination (Cœuré, 2016).

The paper proceeds as follows. Section 2 documents the strong and increasing international co-movement of real and financial variables. Section 3 reviews the main international transmission channels for monetary policy and discusses the main theoretical arguments on how globalisation changes the effectiveness of monetary policy and its implied policy trade-offs. In Section 4 we estimate the size of bilateral monetary policy spillovers between the euro area and the United States and compare them with the respective domestic policy impact. We then turn to the international effects of ECB and Federal Reserve monetary policy in Section 5, and discuss the causes of the asymmetry of spillovers. We conclude in Section 6 with implications for ECB monetary policy and some considerations on the scope of policy coordination between the ECB and the Federal Reserve.

2. Globalisation and international co-movement

It is a commonly held view that globalisation has amplified the international impact of the monetary policy of major advanced economies. This view is motivated by two stylised facts: first, the increase in global trade and financial integration, and second the strong co-movement of key macroeconomic indicators across countries.

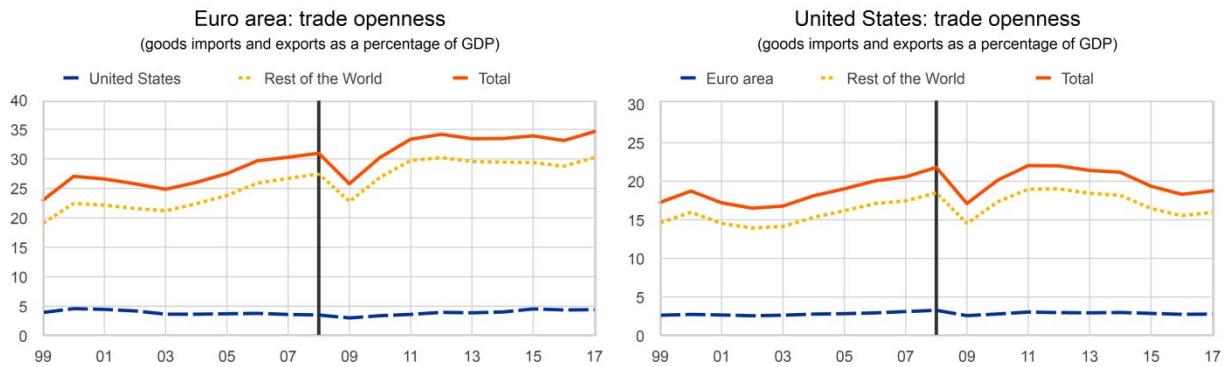**Figure 1: World trade openness and financial integration**
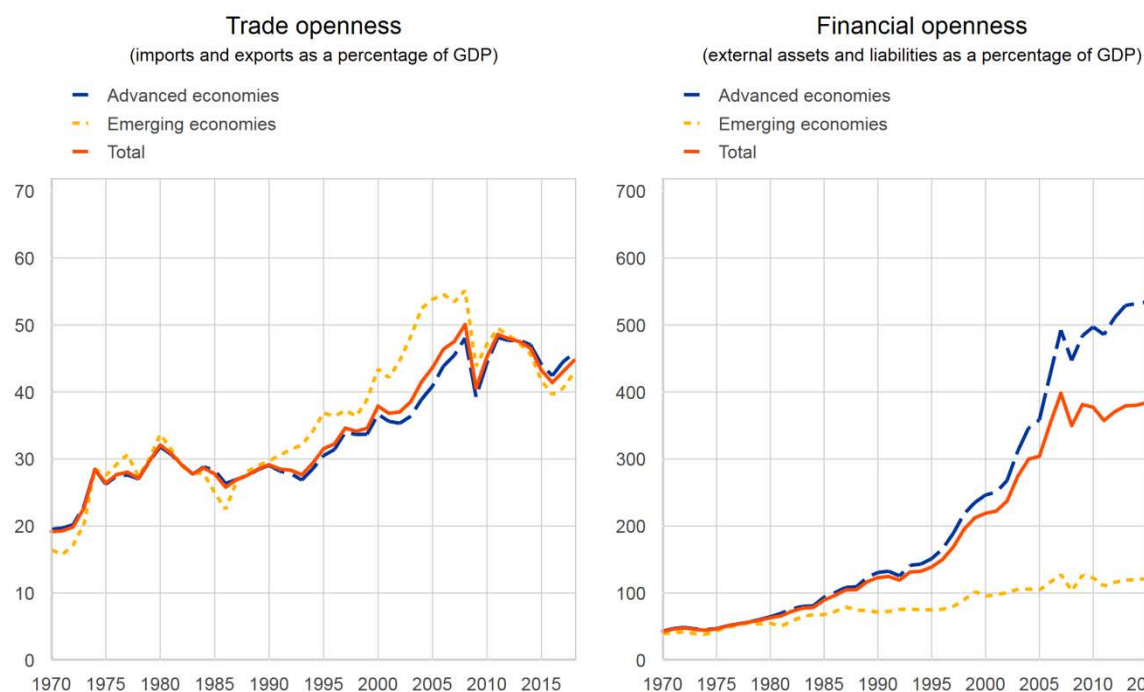
Sources: International Monetary Fund (IMF) Direction of Trade Statistics, Balance of Payments Statistics and External Wealth of Nations database (see Lane and Milesi-Ferretti, 2018).
Notes: The sample consists of an unbalanced panel and includes up to 35 advanced and 34 emerging economies. Trade is defined as merchandise trade.

Trade and financial integration have been rising fast, at least until the global financial crisis. During the 25 years preceding the global financial crisis, world trade was growing approximately twice as fast as world output (Figure 1, left panel). Over the same time period gross foreign asset and liability positions even quadrupled relative to world output (Figure 1, right panel). While the pace of trade and financial integration has slowed more recently, the evidence does not suggest that there are irreversible "de-globalisation" forces at play.

Figure 2: Euro area and US trade openness and financial integration

Euro area: trade openness
(goods imports and exports as a percentage of GDP)

United States: trade openness
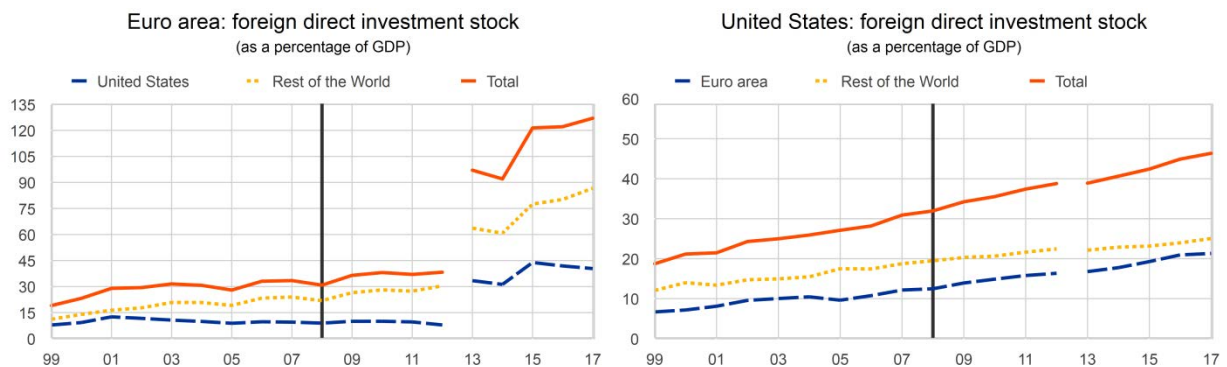(goods imports and exports as a percentage of GDP)

Source: IMF Direction of Trade Statistics.
Notes: The euro area is defined as the 11 original member countries. The vertical line in 2008 indicates the drop in gross trade amid the global financial crisis.
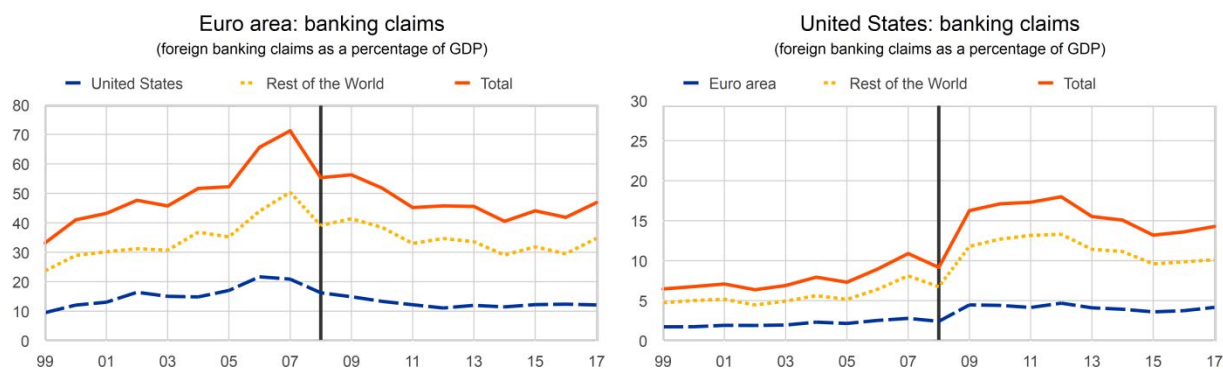
Euro area: portfolio investment
(portfolio assets and liabilities as a percentage of GDP)

United States: portfolio investment
(portfolio assets and liabilities as a percentage of GDP)
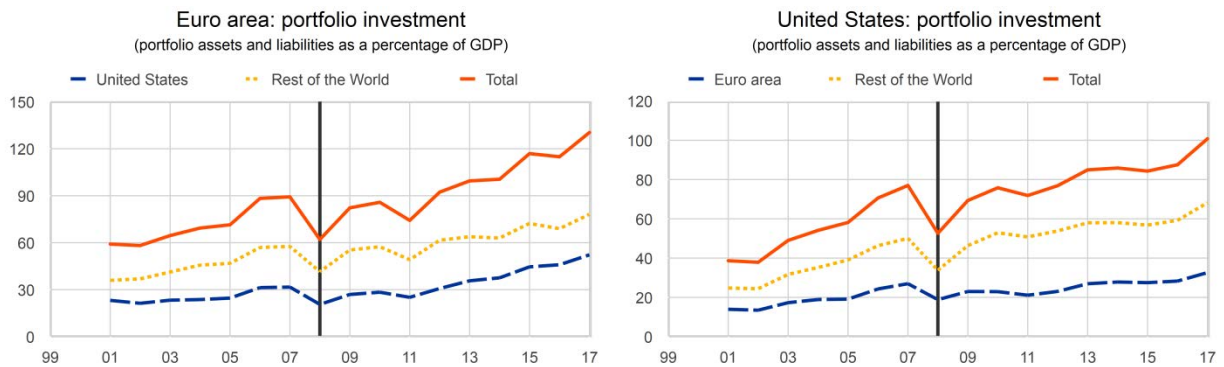
Source: IMF Coordinated Portfolio Investment Survey.
Notes: The euro area is defined as the 11 original member countries. The vertical line in 2008 indicates the drop in portfolio investment amid the global financial crisis.

Euro area: foreign direct investment stock
(as a percentage of GDP)

United States: foreign direct investment stock
(as a percentage of GDP)

Source: Organisation for Economic Co-operation and Development (OECD).
Notes: The euro area is defined as the 11 original member countries. In 2013 the methodology was changed from the third to the fourth Edition of the OECD's Benchmark Definition of Foreign Direct Investment. The vertical line in 2008 indicates the global financial crisis.

<div align="center">

Euro area: banking claims
(foreign banking claims as a percentage of GDP)

United States: banking claims
(foreign banking claims as a percentage of GDP)

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*Source: Bank for International Settlements*
Notes: The euro area is defined as the 11 original member countries. The vertical line in 2008 indicates the drop in banking claims amid the global financial crisis.

Contrary to widely held beliefs, trade and financial integration was not reversed – the main exception being the retrenchment of the international exposure of euro area banks. Apart from a brief dent in 2008, euro area trade integration and portfolio investment have both resumed, now even exceeding the levels recorded before the global financial crisis (Figure 2). While euro area trade with the United States has remained largely unchanged during the last 15 years, its trade with the rest of the world plateaued only after 2012. Portfolio and foreign direct investment continue to increase vis-à-vis all countries. In contrast, euro area foreign banking claims have declined since 2007 as part of a broader process of deleveraging of the banking sector (Figure 2, last row).[5] Analogous evidence can also be found for US trade openness and for US financial integration vis-à-vis the euro area and the rest of the world (Figure 2, right column). The euro area is somewhat more integrated in trade and international finance than the United States, although the difference is not large. One main difference is that the decline in US banking claims started later – only in 2012 – and has been less sizeable in view of the smaller international role of the US banking sector before the global financial crisis.

Key macroeconomic variables have been co-moving strongly (Figure 3). During both 1990-2002 and 2003-2018 inflation was positively correlated across country pairs. While the median bilateral correlation for all country pairs remained broadly unchanged at around 0.4 across these sample periods, the bilateral correlation between inflation in the euro area and in the United States rose from 0.7 to 0.9. Even more remarkable are the patterns in bilateral real GDP growth correlations: while real GDP growth was on average uncorrelated across countries in the earlier sample period – and even negatively correlated between the euro area and the United States – the correlations were large and positive in the more recent sample period.

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[5] See also McCauley et al. (2017).

Figure 3: Distribution of pairwise cross-country correlations of inflation and GDP growth
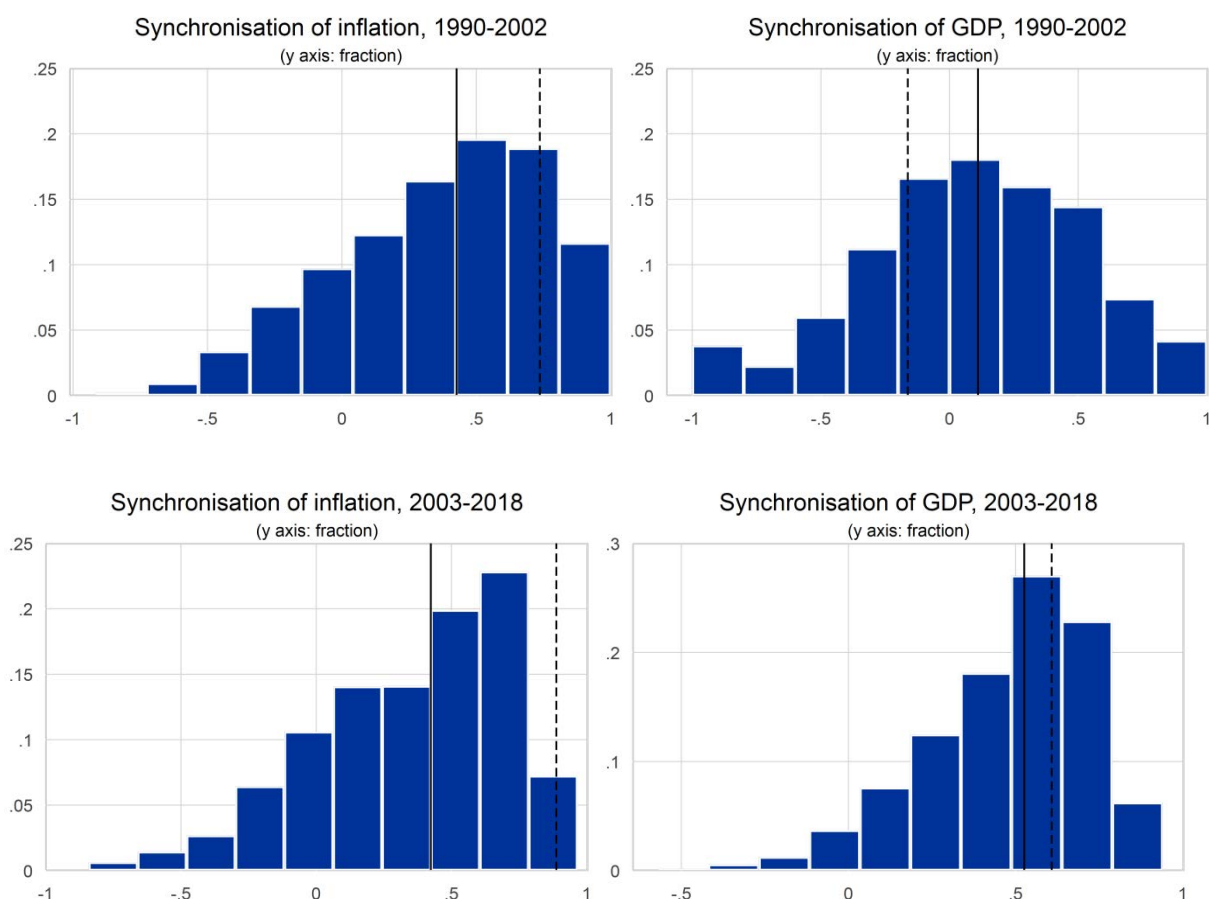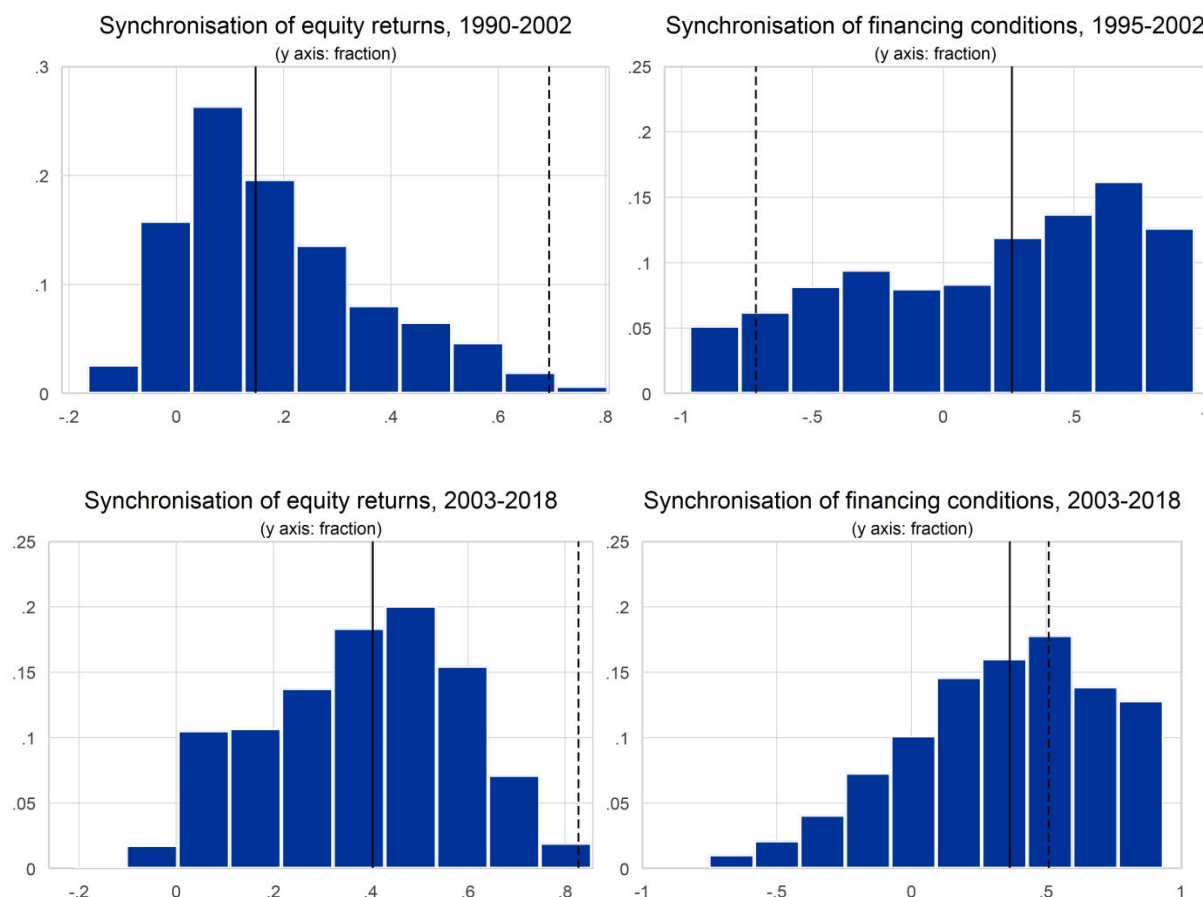

Source: World Bank (World Development Indicators).
Note: The solid line indicates the median correlation and the dashed line the correlation between the United States and the euro area. The data covers 53 advanced and emerging economies at annual frequency.

Financial variables have also become more synchronised across countries, especially between the euro area and the United States (Figure 4). Over the period 2003-2018 almost all national stock markets were positively correlated. The correlation was particularly strong between the stock markets of the United States and the euro area – standing at above 0.8. Similarly, financing conditions co-moved generally more strongly in this period than in 1990-2002. In particular, the correlation between euro area and US financing conditions increased from a negative value to around 0.5 in the more recent sample period. An example of the increasing international dimension of formerly local financial conditions is bond issuance in foreign denominations.

Figure 4: Distribution of pairwise cross-country correlations of equity returns and changes in financing conditions


Sources: Bloomberg and IMF Global Financial Stability Report.
Note: The solid line indicates the median correlation and the dashed line the correlation between the United States and the euro area. Equity prices are represented by the S&P 500 index for the United States and the Euro Stoxx index for the euro area. The sample covers 43 countries for financing conditions and 49 countries for equity returns at monthly frequency. Financing conditions indices are calculated by ECB staff extending the IMF Global Financial Stability Report (April 2017) methodology using a set of nine financial variables.

Globalisation has increased the foreign component in both euro and US dollar bond markets. Figure 5 shows the share of new bonds issued in countries outside the area of the currency in which the bond is denominated. The solid blue line, for example, shows the evolution of the share of euro-denominated bonds that are issued outside of the euro area. Today about 30% of both euro- and dollar-denominated bonds are issued outside of the respective currency area. This vividly illustrates that the monetary policies of the ECB and the Federal Reserve matter not only for financial conditions at home, but also for financial conditions in other countries. Globalisation appears to have increased the foreign component in both bond markets since that the turn of the century.

Figure 5: Share of new bonds issued outside the area of the bond's denomination currency
(percentages of total issuance of bonds denominated in that currency, 12-month moving averages)
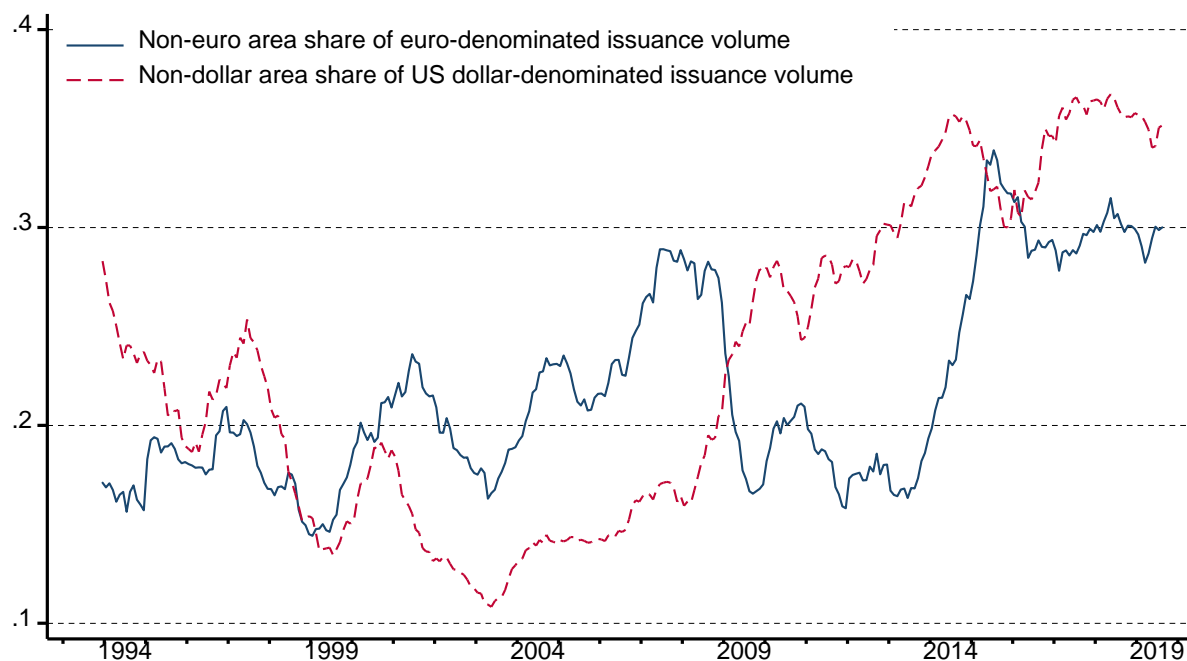
Sources: Dealogic and ECB calculations.

To summarise, despite some slowdown in the pace of integration, the global economy continues to be characterised by a high degree of trade and financial integration as well as by a strong synchronisation of key macroeconomic and financial variables. Deepened trade and financial integration imply that while pursuing national objectives the monetary policies of major advanced economies may have a large impact on the rest of the world through spillovers.

3. The transmission of monetary policy spillovers in a globalised world

We now turn to the origins of this strong synchronisation of key macroeconomic and financial variables, in particular on the question of whether monetary policy in major economies plays a role. Various sources can generate such synchronisation, for example common shocks and cross-border policy spillovers. In this section we review the main international transmission channels of monetary policy and how they are affected by the increased real and financial integration in a globalised world.

In the home economy, monetary policy is transmitted to prices and quantities by affecting domestic financial conditions. In particular, it is able to steer the rates of return on a wide range of assets, in particular the interest rates for different maturities and borrower types. Domestic consumption and investment respond to such changes in financial conditions. In turn, the changes in aggregate demand induce firms to adjust their demand for labour (and other factors of production). The ensuing changes in factor prices (e.g. wages for labour, interest rates for capital as well as prices of raw materials and intermediate inputs), combined with the changes in aggregate demand, influence firms' pricing decisions and thus ultimately the rate of consumer price inflation.

When goods and asset markets are integrated internationally, home monetary policy can affect other economies as well. In particular, when the home economy is integrated with other economies through trade in goods and financial assets, monetary policy actions initiated to steer the home economy can have cross-border repercussions or "spill over" to the rest of the world.

Monetary policy spillovers propagate mainly via three channels: an aggregate demand channel, an expenditure-switching channel and a multi-faceted financial channel. In the following, we explain the mechanisms underlying each of these transmission channels. We describe here the effects of a *home* monetary policy *tightening*, the scenario for which we estimate the spillovers for the ECB and the Federal Reserve in the data in Sections 4 and 5.

3.1. Aggregate demand channel

Monetary policy spillovers through the aggregate demand channel are transmitted to the rest of the world via trade. In a closed economy, domestic aggregate demand is the same as domestic output. In an open economy which trades with the rest of the world, a part of aggregate demand will be for imports.[6] The degree of "openness" to imported goods depends on technological and "man-made" trading frictions, such as transportation and information costs (including costs due to language and taste differences), as well as tariff and non-tariff barriers (e.g. due to regulation). To the extent that a contractionary monetary policy action curbs home consumption and investment, it also reduces the demand for imported goods, and thus for exports of the economy's trading partners. As a result, spillovers through the aggregate demand channel reduce output in the trading partner countries. The

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[6] Moreover, intermediate inputs and some services can be imported from abroad. In the following, our use of the term "goods" includes all of these.

magnitude of the monetary policy spillover through the aggregate demand channel rises with the weight of the home economy in its trading partners' overall trade. Because the foreign effect has the same sign as the domestic effect, the spillovers materialising through the aggregate demand channel are labelled "positive". Monetary policy of economies with a large weight in the global economy can thus affect aggregate demand worldwide.

Spillovers through the aggregate demand channel have arguably grown with the deepening of trade integration. A notable aspect of globalisation has been to reduce trade barriers across economies, increasing the share of imported goods and services in aggregate demand (including demand for intermediate inputs). Nevertheless, these direct and positive aggregate demand spillovers can be dampened or even overturned by monetary policy spillovers mediated through exchange rates, to which we now turn.

3.2.   Expenditure switching channel

The expenditure-switching channel for monetary policy spillovers works via the influence of the exchange rate on the relative price between home and foreign goods. A key determinant of the demand for imports (and hence the exports of trading partners) is the relative price between goods produced at home and abroad. The relative price between domestically produced goods and imports may change if the exchange rate between the currencies responds to monetary policy actions while the prices are sticky in the different currencies. In this way, exchange rates change the competitiveness of domestic relative to foreign producers. Monetary policy actions which change the relative price between home and foreign goods lead to expenditure switching and thereby affect the trade balance.

A home monetary policy tightening tends to lead to an appreciation of the economy's nominal exchange rate. The exchange rate between two currencies reflects current and expected (short-term) interest rate differentials, as well as currency risk premia. A monetary policy tightening which shifts up the yield curve in the home economy relative to its foreign counterparts hence triggers – all else being equal – an instantaneous exchange rate appreciation.[7]

How a nominal appreciation of the home currency affects the relative price between domestically produced goods and imports depends on the degree of exchange rate pass-through. In other words, it depends on how much the price of imports expressed in the currency of the importer changes following a change in the nominal exchange rate. Exchange rate pass-through is not necessarily complete and instantaneous, i.e. exchange rate changes do not necessarily translate one-to-one into changes in local-currency import prices.

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[7] At short horizons, currency risk premia are empirically correlated with interest rate differentials for advanced economies, so that the exchange rate appreciation following a monetary policy tightening is generally stronger than what is implied by increases in current and expected interest rates (see Engel, 2016b), creating a deviation from the uncovered interest rate parity.

A key determinant of exchange rate pass-through over shorter horizons is the currency in which import prices are set and how frequently these prices are adjusted, i.e. how "sticky" they are. We can distinguish three stylised pricing paradigms, assuming here for simplicity of exposition that they apply to all countries. First, all exports are priced in the currency of the exporter; second, all exports are priced in the currency of the importer; and third, all exports are priced in the same currency, which will necessarily in many cases not be the currency of either of the trading partners.[8]

Under the first pricing paradigm, export prices are sticky in the currency of the producer, exchange rate pass-through is full and a nominal exchange rate appreciation of the home currency induces expenditure switching away from domestically produced goods and towards goods produced in the rest of the world. A monetary policy tightening at home that is followed by a nominal exchange rate appreciation makes home goods less competitive and foreign goods more competitive. This induces expenditure switching away from home goods and towards foreign goods both abroad and at home. Abroad, the nominal exchange rate appreciation induces expenditure switching away from goods produced in the home economy – i.e. away from the home economy's exports – towards goods produced in the rest of the world. At home, the nominal exchange rate appreciation induces expenditure switching away from domestically produced goods and towards goods produced in the rest of the world – i.e. towards imports.

In the rest of the world the expenditure-switching channel works against the aggregate demand channel. In the home economy, this expenditure switching from goods produced in the home economy and towards goods produced in the rest of the world adds to the contractionary pressure on output and inflation that arise through aggregate demand effects. In the rest of the world, however, it dampens the corresponding downward pressures on output and inflation. The boost to foreign output and the increase in foreign currency import prices can push up foreign inflation – potentially to the point that their increase more than offsets the aggregate demand channel.

The case in which export prices are sticky in the currency of the producer is commonly referred to as producer-currency pricing (PCP). PCP is the traditional Mundell-Fleming price stickiness paradigm commonly (and implicitly) referred to in textbooks and public discussions about the expenditure-switching effects of exchange rate variation.[9] Under PCP the sign of the spillovers through the expenditure-switching channel from home monetary policy to output and inflation in the rest of the world is opposite to the sign of the domestic effects, implying a "negative" spillover. A home monetary tightening widens the home trade deficit because, while exports and imports both fall, imports are propped up by expenditure switching towards foreign goods and thus fall less.[10] Compared with a closed

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[8] International trade displays a wide range of mixtures of these three stylised cases. For example, for a given country, different pricing rules might apply to imports and exports. Which combination of the effects described for the three stylised cases dominates depends on the relative currency and trade shares.
[9] See Fleming (1962), Mundell (1963), and also Obstfeld and Rogoff (1995).
[10] See, e.g., Corsetti and Pesenti (2001).

economy, the contractionary domestic effects of the monetary policy tightening on domestic output and inflation are amplified.

Under the second pricing paradigm, export prices are sticky in the currency of the importer, and exchange rate pass-through and monetary policy spillovers through expenditure switching are muted.[11] In this case the effect of monetary policy on the exchange rate is not passed through to prices. The relative price of imports and domestically produced goods remains unchanged, and hence no expenditure switching occurs.

The case in which export and import prices are sticky in the currency of the importer is commonly referred to as local-currency pricing (LCP). In this case the expenditure-switching channel is largely muted, and the exports of the home economy and the inflation in the rest of the world remain unchanged. The imports of the home economy (and thus its trade balance) and output in the rest of the world are not affected by expenditure switching either, but they may change as a result of aggregate demand changes. Compared with a closed economy (and therefore also compared with the PCP case) the effects of monetary policy under LCP are smaller – both at home and abroad. The net effect of monetary policy is dominated by aggregate demand: after a home monetary policy tightening, the home trade balance is likely to improve initially because the demand for imports is depressed via the aggregate demand channel, and hence foreign output falls. The overall impact on the trade balance is ambiguous, however, because the appreciation of the exchange rate deteriorates the terms of trade.

Under the third pricing paradigm, all export (and import) prices worldwide are sticky in a single currency, and expenditure switching depends on the source of the shock and on the specific bilateral trade relationship in question. In this pricing paradigm, the dominant currency is also used in trade relationships that do not include the country issuing the currency. For countries outside the dominant-currency area, all export (and import) prices are sticky in the dominant currency regardless of destination (and origin).

The case in which all trade prices are sticky in the same currency is commonly referred to as dominant-currency pricing (DCP). For example, in the dominant-currency issuing economy a multilateral appreciation of its currency is inconsequential in terms of expenditure switching at home, as import prices are sticky in its own currency. In the entire rest of the world, by contrast, a multilateral appreciation of the dominant currency entails a widespread rise in import prices, which induces expenditure switching away from imports and towards domestically produced goods. Importantly, this expenditure switching in all economies in the rest of the world affects imports from all sources and not only from the dominant-currency issuing economy. Moreover, because imports in economies in the rest of the world decline regardless of the source, rest of the world exports decline commensurately (including in the dominant-currency issuing economy). Overall, monetary policy in the dominant-currency issuing economy drives (gross) global trade.

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[11] See Betts and Devereux (1996, 2000) as well as Devereux and Engel (2003).

Under dominant-currency pricing, the exchange rate pass-through to import prices is muted in the dominant-currency issuing economy but complete everywhere else. A monetary tightening in the dominant-currency bloc thus creates inflationary pressures around the world. [12] [13]

Recent research suggests that trade prices are sticky in the currency of invoicing. Data on the invoicing structure of global trade allow an empirical assessment of which of these pricing paradigms is most relevant. Gopinath et al. (2020), Zhang (2018) and Georgiadis and Schumann (2019) provide evidence that trade invoicing patterns indicate the currency in which trade prices are sticky in a global sample of countries. Earlier evidence focusing on individual countries is consistent with these findings. For example, Gopinath and Rigobon (2008) document that US import and export prices are rigid for significant durations in their currency of invoicing; Fitzgerald and Haller (2014) provide similar evidence for Irish export prices and Friberg and Wilander (2008) for Swedish export prices.

Figure 6: Currency shares in global trade invoicing
(shares of total)

a) Exports

b) Imports
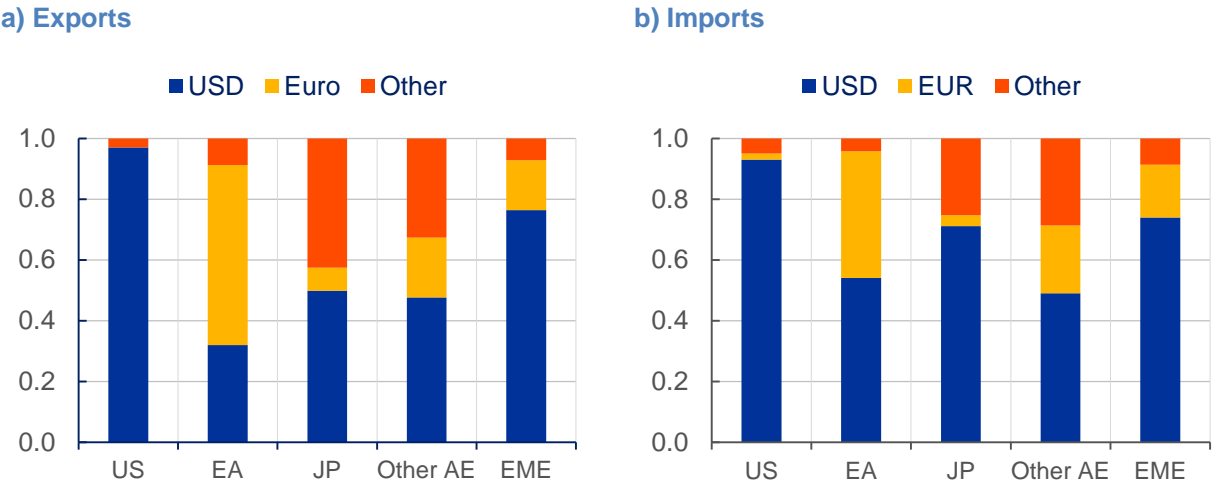
Sources: Gopinath (2015), Eurostat and ECB calculations.
Notes: EA stands for euro area; AE stands for advanced economies; EME stands for emerging market economies.

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[12] An additional transmission channel for monetary policy spillovers from the dominant-currency issuing economy to the rest of the world operates through the endogenous response of monetary policy: as all of economies' import prices in the rest of the world are sticky in the dominant currency – regardless of their source – a multilateral appreciation of the dominant currency raises local currency import prices and thereby consumer price inflation; depending on the degree of openness, this might induce local monetary policy to tighten, putting downward pressure on production (see Mukhin, 2018, and Zhang, 2018).

[13] In contrast, multilateral appreciation of a non-dominant currency has only limited effects. In the economy issuing this non-dominant currency expenditure switching affects only imports, but not exports. Trade in the rest of the world that does not involve this economy is entirely unaffected by the multilateral appreciation of its non-dominant currency.

The US dollar is currently the dominant invoicing currency in global trade (Gopinath, 2015)**.** Especially emerging economies invoice the bulk of their imports and exports in US dollars (Figure 6), regardless of the destination. The large share of global trade invoiced in US dollars and the evidence for the coincidence of the invoicing currency with the currency in which trade prices are sticky is suggestive evidence for the empirical relevance of dominant-currency pricing.

The effect of globalisation on the expenditure-switching channel is ambiguous. On the one hand, deeper trade integration, with a growing share of imported intermediate inputs in production, assimilates firms' production costs across countries, which reduces the competitiveness effects of exchange rate movements, even under complete exchange rate pass-through (Gust et al., 2010; Georgiadis et al., 2019). On the other hand, more similar cost structures across firms in different countries can induce firms to coordinate with one another – setting in equilibrium their export prices in the same dominant currency (Mukhin, 2018). More widespread use of a single currency in global trade amplifies the spillovers from monetary policy of the economy issuing that currency.

3.3. Financial channel

Under international capital mobility, home monetary policy can affect foreign financial conditions, giving rise to a financial channel of monetary policy spillovers. The financial channel rests on the ability of domestic firms, financial intermediaries and households to trade domestic and foreign assets with the rest of the world. As a consequence of international capital mobility, saving and consumption decisions of home agents will reflect the returns on both domestic and foreign assets. In fact, in the textbook international monetary model, perfectly integrated international financial markets allow agents to borrow and lend at both domestic and foreign real interest rates. Generally, domestic and foreign real rates will differ to the extent that consumption baskets and prices are different across countries (because of non-traded goods, for example), even under perfect financial integration. But via their fundamental determinants, such as aggregate world savings, they are related and possibly synchronised. In a financially integrated world, monetary policy in a large currency area that influences global financial conditions will affect real aggregate demand in the rest of the world, bringing about another multi-faceted channel of monetary spillovers.[14]

One component of the financial channel works through the influence of monetary policy on the yield curve in the rest of the world. In particular, this component of the financial channel works through foreign demand for certain "special" home assets, in particular when these assets are perceived to be "safe" (see e.g. Farhi and Maggiori, 2018). When a country supplies a global safe asset, thus enjoying a dominant position in global financial markets, its monetary policy is very likely to have a direct effect on

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[14] In the limit case of a common world real interest rate (which requires complete international markets and identical consumption baskets), the home monetary authority which sets the domestic nominal interest rate will still be able to determine domestic inflation under flexible exchange rates. But it cannot determine the level of domestic real activity even in the presence of nominal rigidities (see Woodford, 2009). Therefore, financial integration can limit the effects of home monetary policy on real activity but not on inflation.

aggregate demand abroad: a home monetary policy tightening increases the global demand for home assets and thus directly reduces global aggregate demand.[15]

A second component of the financial channel involves exchange rates, which determine the relative valuation of financial assets denominated in different currencies. The increase in the holdings of foreign assets shown in Figure 1[16] has accentuated the importance of exchange rate valuation effects via the financial channel of monetary policy spillovers.

Exchange rate changes can give rise to cross-border wealth effects. To be specific, let us assume that foreign assets are denominated in the currency of the debtor economy. In response to an appreciation of the home currency triggered by a tightening of domestic monetary policy, the home currency price of foreign assets falls. This wealth effect depresses domestic spending, amplifying the domestic effects of the monetary policy tightening through the aggregate demand channel (Meier, 2013). At the same time, the foreign currency value of the home economy's foreign liabilities held by the rest of the world increases in response to this currency appreciation. Hence, exchange rate valuation effects on foreign economies' foreign asset holdings lead to spillovers of the opposite sign relative to the domestic effects.

When foreign assets and liabilities are denominated in a globally dominant currency regardless of the debtor economy, spillovers from the dominant-currency-issuing economy through exchange rate valuation effects can be particularly powerful. In particular, if many countries have issued financial assets denominated in a dominant currency, then the monetary policy of the issuing country has spillovers to the entire (rest of the) world even beyond its own foreign liabilities. In particular, if the dominant currency appreciates multilaterally, the local-currency value of all dominant-currency foreign assets and liabilities of other economies rises, regardless of whether these involve the dominant-currency issuing economy as debtor or creditor. Obviously those economies with an external balance sheet that is net long in foreign currency experience an exchange valuation gain, stimulating production and inflation. In contrast, economies with a net short position experience a valuation loss, putting downward pressure on their production and inflation. Hence, the sign of the spillovers from monetary policy in the dominant-currency issuing economy through this component of the financial channel depends on economies' net foreign currency exposure (Lane and Shambaugh, 2010; Georgiadis and Mehl, 2016).[17]

Such valuation effects change also the value of collateral denominated in foreign currency, and thereby borrowing and leverage.[18] A home currency appreciation will then tighten borrowing

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[15] This applies even if the safe asset is a short-term asset.

[16] Despite which cross-country risk sharing remains incomplete.

[17] Many studies have explored the emergence of international, dominant and reserve currencies, see for example Maggiori (2017), Eren and Malamud (2018), Gopinath and Stein (2018), and Mukhin (2018).

[18] Bruno and Shin (2015b) describe the consequences of the co-movement of US dollar exchange rates and the leverage of global banks. They refer to this relationship between domestic and global financial conditions as the "risk-taking channel of [local] currency appreciation". See Kearns and Patel (2016), Hofmann et al. (2017) as well as Avdjiev et al. (2018) for empirical evidence.

constraints and reduce domestic borrowing capacity. For instance, this can occur when borrowing capacity is proportional to the value of current and expected domestic tradable output (see Corsetti et al., 2018).

A third component of the financial channel works through the balance sheet exposure of highly leveraged investors, spreading financial stress across borders. A monetary policy tightening depresses the value of domestic assets via a higher discount factor and lower expected cash flows. Some holders of these assets are leveraged investors, including financial intermediaries. The decline in asset values tightens their balance sheet constraints, which is why this transmission channel is also called the "balance sheet" channel.[19] For highly leveraged investors, these constraints start to bind after relatively small asset price movements. Their balance sheets can deteriorate to the point that they are forced to deleverage and reduce their lending and investment. In a financially integrated world economy, both home and foreign financial intermediaries can potentially spread the contractionary impact of home monetary policy across borders: home intermediaries, if they are an important source of funding abroad, and foreign intermediaries, if they are highly exposed to home assets (whose value is depressed by the home monetary tightening).

A factor complementary to the balance sheet exposure mechanism is the international propagation of shocks via asset price equalisation and the synchronisation of credit spreads and borrowing costs of leveraged cross-border investors. In order to finance their holdings of domestic and foreign capital, investors will have to pay a spread over the (nominal) risk-free rate which is an inverse function of their net worth (or equity). On the one hand, to the extent that the same set of risky assets is freely traded across countries, (expected) returns on each type of capital investment will be the same for all investors. On the other hand, optimality of investors' decisions will require that the returns on domestic and foreign capital be equalised to the domestic cost of raising funds. As a result, by force of arbitrage, borrowing costs will tend to display similar dynamics even in segmented, exclusively domestic markets. In turn, when financial integration in the market for risk-free bonds is also considered, leading to the equalisation of this component of borrowing costs, the combination of these integrating forces in different asset classes will imply that even the credit spread is equalised across countries. Credit spread increases in one country due to a monetary policy tightening will therefore spill over to other countries and increase credit spreads abroad, potentially resulting in strong co-movements in asset prices, demand for capital, investment and real activity, even with limited exposure to foreign assets and substantial degrees of financial home bias in asset holdings.[20] This highlights another source of

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[19] When applied to banks, the balance sheet channel is also dubbed the bank-lending channel (Bernanke and Gertler, 1995).

[20] By affecting borrowing constraints, monetary policy spillovers can impinge on financial stability in the rest of the world – see Borio and Zhu (2012), who call this the "risk-taking channel" of monetary policy. Global banks play an important role in this international transmission of the domestic financial stability stance (Bruno and Shin, 2015a). By shifting their funding sources from one country to another, they spread financing conditions, credit standards and risk across borders (Cetorelli and Goldberg, 2012). Note that this mechanism also works for shocks other than monetary shocks that influence credit spreads.

international propagation that grows with deepening financial integration (see e.g. Dedola and Lombardo, 2012, and Devereux and Yetman, 2010).

Figure 7: Issuance volume of bonds outside the home currency area
(EUR billions, 12-month moving average)
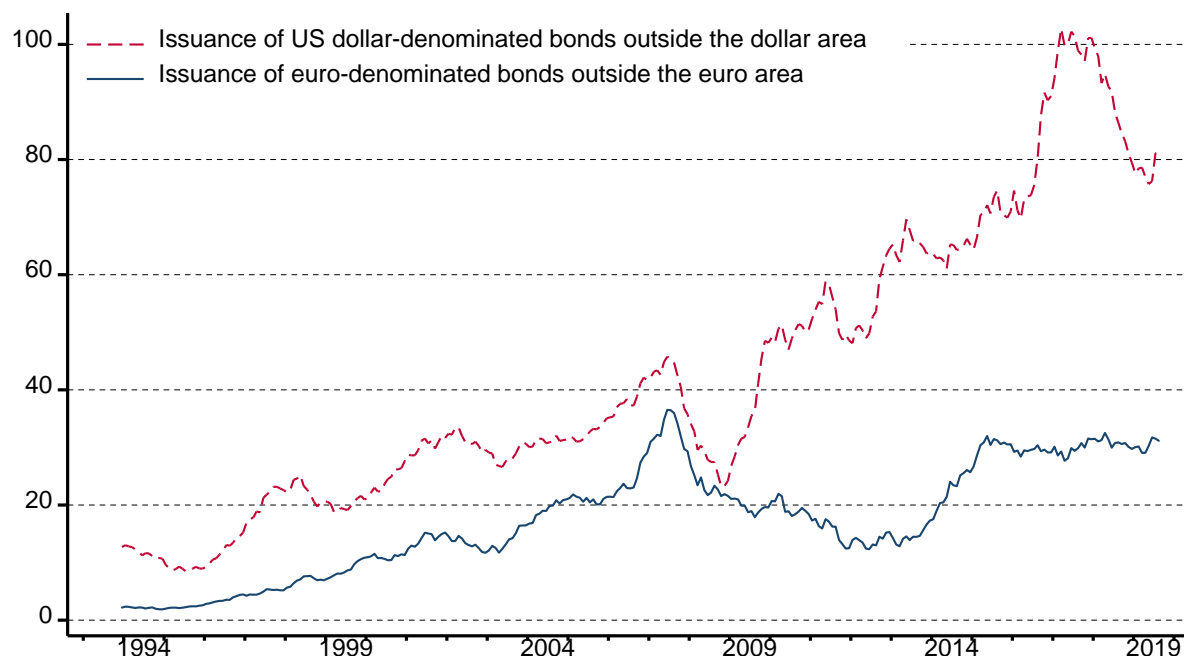
Sources: Dealogic and ECB calculations.

Global financial markets are dominated by securities denominated in US dollars. The similar internationalisation of euro and US dollar bond markets shown in Figure 5 would suggest a similar role for the ECB and Federal Reserve in global financial conditions. But this is not the case. Figure 7 reveals why. It shows the issuance volume of bonds outside of their home currency area. Since 2009 the US dollar bond market has been about three times as large as the euro bond market.[21] As a result, and as is the case for global trade, the US dollar is a globally dominant currency in financial markets.

Financial globalisation is likely to have amplified the spillovers from monetary policy. For example, in the low interest rate environment, emerging economy corporates, especially, have issued large amounts of US dollar debt (Bank for International Settlements, 2019). Several international organisations and policymakers have pointed to the vulnerabilities these exposures might pose once normalisation of Federal Reserve monetary policy is complete.

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[21] This difference re-emerged after the sovereign bond crisis. Since then, the euro's relevance in bond markets has been falling behind that of the US dollar, enforcing the dominant role of the United States in global financial conditions. In the period up to the year 2007, both euro and dollar bond markets grew rapidly. The euro market grew disproportionally strongly, boosted by the strong euro appreciation, so that by 2007-08 it had largely caught up with the dollar bond market. But after the sovereign bond crisis, the euro bond market only recovered to pre-crisis levels, whereas the dollar bond market kept growing at a constant rate.

4. Empirical analysis of the spillovers between the euro area and the United States

Globalisation has strengthened all three international transmission channels, but as the review of theory in the previous section shows their effects can offset each other. Assessing their net effect is therefore an empirical question. In the next two sections we explore the importance of these channels for the international transmission of ECB and the Federal Reserve monetary policy.

Separate studies have documented strong international effects of Federal Reserve and weaker effects of ECB monetary policy. Mackowiak (2007), Feldkircher and Huber (2016), Georgiadis (2016), Dedola et al. (2017), Dées and Galesi (2019), Degasperi et al. (2019) and Iacoviello and Navarro (2019), for example, show large spillovers from Federal Reserve monetary policy to Europe and, especially, to emerging economies – often larger than its domestic effect in the United States. The international effects of ECB monetary policy have received attention only recently, typically in the context of spillovers from unconventional monetary policy to emerging Europe and other emerging markets (e.g. Babecká-Kucharčuková et al., 2016; Bluwstein and Canova, 2016; Potjagailo, 2017; Benecká et al., 2018; Moder, 2019).

Unfortunately, this literature does not allow a direct comparison of ECB and Federal Reserve monetary policy spillovers. In particular, existing studies typically focus on spillovers from a single central bank. Because these studies differ in terms of sample period, estimation methodology and the identification approach, a consistent comparison of their estimates of ECB and Federal Reserve monetary policy spillovers is not possible. Systematic comparisons of the spillovers from ECB and Federal Reserve monetary policy are rare. Exceptions are Rogers et al. (2014) and Chen et al. (2017), but both of these studies focus on unconventional monetary policies, and the former additionally on spillovers at higher frequencies.

Furthermore, the spillovers documented in these studies are not necessarily a result of monetary policy. In the literature interest rate surprises around monetary policy announcements are commonly assumed to reflect monetary policy shocks.[22] Jarociński and Karadi (2020) show, however, that a non-trivial component of these surprises in fact reflects central bank information shocks, i.e. changes in the public's beliefs about the state of the economy induced by a monetary policy announcement without a change in the monetary policy *stance* per se. As a result, existing estimates of monetary policy spillover might be contaminated by the spillovers from such central bank information shocks.

For these reasons we analyse the spillovers from ECB and Federal Reserve monetary policy shocks in one coherent framework and carefully isolate interest rate shocks from shocks unrelated to monetary

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[22] Hoek et al. (2019) show that the magnitude of spillover from US monetary policy to emerging economies depends on the underlying shock. Specifically, if the Federal Reserve responds to rising inflation it generates larger spillovers than if it responds to accelerating economic growth.

policy. We start in this section with an empirical analysis of bilateral spillovers between the euro area and the United States.

4.1 Estimating the effects of monetary policy

Estimating the effects of monetary policy is complicated, because monetary policy not only affects the state of the economy, but also responds to it. Most changes in monetary policy are a reaction to a change in the state of the economy, rendering monetary policy endogenous. As a consequence, consistent estimation of the effects of monetary policy needs to address the well-known endogeneity problem. To do so, we consider only exogenous changes in monetary policy that are unrelated to changes in the business cycle.

We construct exogenous interest rate surprises from movements in financial markets over narrow time windows around monetary policy announcements. The basic idea of this identification approach is that in a sufficiently narrow time window it is unlikely that events besides the monetary policy announcement itself have driven financial markets. Therefore the movements in interest rates over this time window represent the financial market effect of the monetary policy announcement, i.e. the interest rate surprise. If financial markets had anticipated a change in the monetary policy stance, e.g. as part of endogenous monetary policy, it would have already been priced in before the announcement and thus interest rates would not have moved systematically during the narrow time window. Conversely, if interest rates have moved, this reflects the fact that financial markets were surprised by the monetary policy announcement, i.e. that this movement in rates is exogenous.

The interest rate surprises around a monetary policy announcement might be contaminated by a central bank information effect and thus not be a pure monetary policy shock. A central bank can move financial markets not only by surprises in its monetary policy stance given fundamentals, but also by affecting public beliefs about the these fundamentals. In the first case, financial markets react to a surprise announcement that monetary policy is tightened or loosened, without inducing a reassessment of current fundamentals. In the second case, they react to the information that the central bank holds a more optimistic view of fundamentals than anticipated. In this case, the interest rate surprise reflects a release of private central bank information about the outlook to the public. This "central bank information effect" (Romer and Romer, 2000; Melosi, 2017; Nakamura and Steinsson, 2018; Cieslak and Schrimpf, 2018) is conceptually very different from a monetary policy shock, and hence it comes as no surprise that its consequences can also be very different. Jarociński and Karadi (2020) have shown that central bank information can distort the estimation of the effects of monetary policy, in particular the persistence of the interest rate response and the magnitude of the price level response. Following their approach we purge these information effects on the basis of the co-movement between interest rates and stock price surprises.

We isolate interest rate surprises from central bank information effects using changes in stock prices. Specifically, when stock prices move in the same direction as interest rates around the time of the

announcement, we label the interest rate surprise a central bank information shock. When, by contrast, stock prices and interest rates move in opposite directions, we classify this as a monetary policy shock. With this approach we take the simplifying assumption that the total interest rate surprise is either entirely a monetary policy shock or entirely a central bank information shock. This approach corresponds to the "poor man's" identification approach of Jarociński and Karadi (2020). However, the results are in general not sensitive to relaxing this assumption. The less restrictive "rotational sign restrictions" approach, under which the total interest rate surprise may be a combination of a pure monetary policy and a central bank information shock, yields similar results. We shall refer to this alternative identification scheme in cases whenever the results diverge in important ways from the baseline.[23]

Our dataset consists of 168 Federal Reserve and 296 ECB monetary policy announcements, which were made between the years 1999 and 2018. The changes in interest rates and stock prices are measured in the time window starting 10 minutes before and ending 20 minutes after a central bank announcement. In the case of the Federal Reserve, the timing of the announcement typically coincides with that of the press release. In the case of the ECB, the time window is generally longer, starting 10 minutes before the press release and ending 20 minutes after the end of the press conference. In these windows we define the Federal Reserve interest rate surprise as the first principal component of the changes in federal funds futures and eurodollar futures with remaining maturities from one month up to one year. Similarly, we define ECB interest rate surprises as the first principal component of the changes in EONIA swaps with maturities from one month up to one year. By including maturities of up to one year, these surprises capture not just current changes in policy rates but also the expectations for interest rates up to one year into the future, capturing forward guidance and other non-standard monetary policy measures.[24]

Monetary policy shocks account only for a small fraction of the total variation of the monetary policy stance reflected in the data. In the case of policy rates, the typical (exogenous) shock in an average

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[23] We aggregate these interest rate surprises to monthly frequency. In our baseline we assume that the (total) shock in any given month is either a pure monetary policy shock or a pure central bank information shock. The "rotational sign restrictions" approach is less restrictive, and assumes that we observe a combination of both types of shock in each month, i.e. that in a typical month each of the two shocks enters with a non-zero weight. The stronger identifying assumption in our set-up turns out to provide a better instrument for ECB monetary policy. For Federal Reserve monetary policy, rotational sign restrictions provide the better instrument. For comparability we show in this paper impulse responses based on the more restrictive approach for both the ECB and the Federal Reserve, but discuss the results from rotational sign restrictions for the Federal Reserve in the text. Jarociński and Karadi (2020) compare the merits of the two identification approaches. See also Appendix A1.

[24] The Federal Reserve surprises come from the updated Gürkaynak, Sack and Swanson (2005) dataset and the ECB surprises from the Jarociński and Karadi (2020) dataset. Similar empirical proxies for monetary policy surprises are used in a large body of literature that includes e.g. Kuttner (2001), Gürkaynak et al. (2005), Bernanke and Kuttner (2005) and many others. To account for forward guidance close to the effective lower bound, we also consider longer-term rates as a robustness check. Extracting ECB monetary policy surprises from movements in three-year overnight index swaps during the effective lower bound period increases the magnitude, but not the time-series pattern, of monetary policy shocks, and therefore the results remain unchanged.

month is only of about 2 or 3 basis points. The estimation of the monetary policy effects may effectively be based on relatively weak instruments, which should be kept in mind when interpreting the results.

A relevant finding is that ECB and Federal Reserve monetary policy shocks are uncorrelated. The systematic components of ECB and Federal Reserve monetary policy respond endogenously to the state of the economy and hence to transatlantic shocks (Belke and Gros, 2005). In contrast, given their exogenous nature, the unsystematic (i.e. surprise) components of ECB and Federal Reserve monetary policy in theory neither influence nor respond to each other. In fact, this is also a feature of the shocks we construct from the data. Therefore, any co-movement between the effects of a given monetary policy shock on the United States and on the euro area must be due to monetary policy spillovers rather than to correlated shocks occurring simultaneously.

4.2   Bilateral spillovers of ECB and Federal Reserve monetary policy shocks

We use the pure monetary policy shocks in a Bayesian vector autoregressive (VAR) model to estimate the effects of monetary policy on the economy. We introduce ECB and Federal Reserve monetary policy shocks into a standard Bayesian VAR model (Sims, 1980) and compute the responses of the modelled variables to the respective shock. In the following we report the responses to a monetary policy tightening of one standard deviation, which corresponds to a contemporaneous increase in domestic one-year bond yields by almost 2.8 basis points for the ECB and close to 2.0 basis points for the Federal Reserve.[25] In Figure 8 and in the following figures we show how key domestic variables respond in the 36 months that follow a policy tightening by the ECB (left column) and the Federal Reserve (right column) on the basis of the impulse responses from the estimated VAR model. All these responses reflect the general equilibrium effects of the exogenous monetary policy shocks, and hence include the effects of the endogenous policy responses of other central banks.[26]

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[25] The ECB and Federal Reserve monetary policy shocks studied here have thus a similar, but not identical, impact on one-year bond yields. To compare monetary policy shocks with a (counterfactually) exactly identical impact, the quantities in the following figures can be rescaled. Such rescaling reduces the relative magnitude of ECB policy impact versus the Federal Reserve policy impact, but does by construction not affect significance. The impulse responses to a monetary policy loosening can be obtained by flipping the sign of the responses, because the model is linear.

[26] Appendix A1 details the specification of the Bayesian VAR models used in this paper. Appendix A2 summarises the definitions of the response variables.

Figure 8: Responses of the bilateral interest rate differential and exchange rate to a monetary policy tightening (bilateral model)
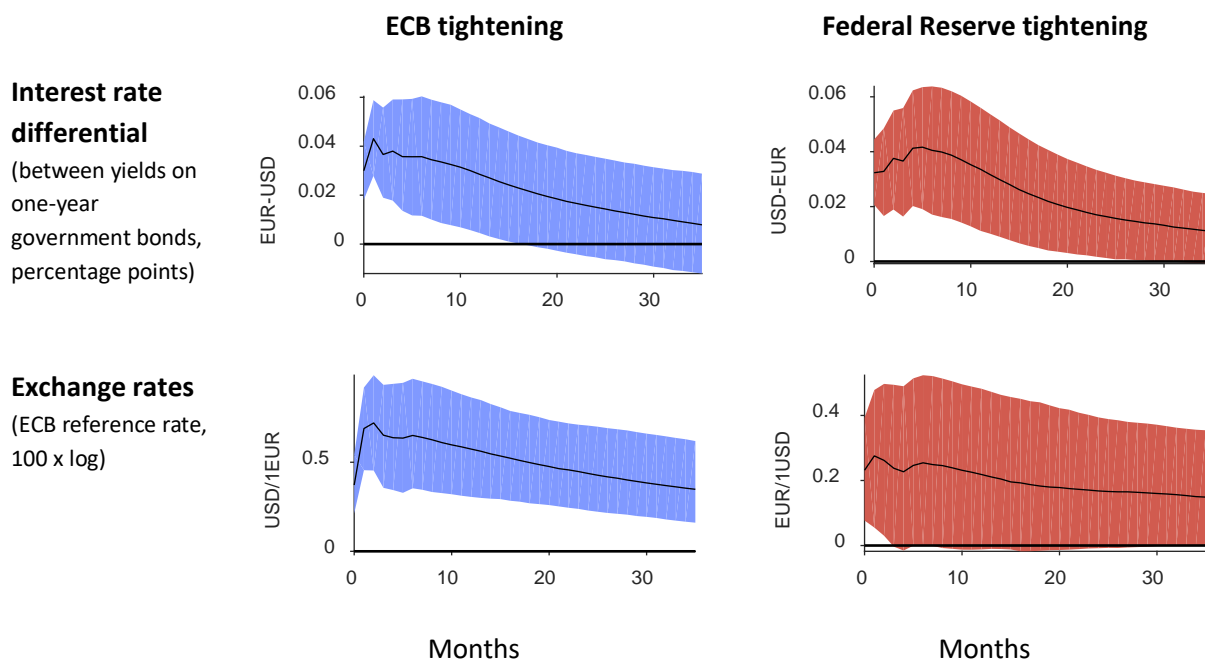
Notes: *The solid line plots the median impulse response, surrounded by the 68% confidence band. The left-hand column shows the responses to an ECB tightening and the right-hand column responses to a Federal Reserve tightening. The quantities in the right-hand column are the inverse of the quantities in the left-hand column. The first row shows the yield differential between a one-year US Treasury and the one-year German Bund.*

In line with economic theory, whenever the ECB or the Federal Reserve tightens its monetary policy, a positive spread opens between domestic and foreign interest rates and the domestic currency appreciates. Figure 8 plots the point estimate of the impulse response as solid line, surrounded by the 68% confidence band as shaded area. After both an ECB tightening and a Federal Reserve tightening the interest rate differential between the two regions (defined as home minus foreign government bond rate) widens significantly.[27] The first row of Figure 8 shows very similar magnitude and persistence for both monetary policy shocks on the interest rate differential for one-year bonds. In line with uncovered interest rate parity, the domestic currency appreciates in both cases because domestic interest rates increase relative to foreign rates. After an ECB monetary policy tightening the euro appreciates particularly sharply against the US dollar. Likewise, after a Federal Reserve monetary policy tightening the US dollar appreciates as well, but its upward movement is smaller and less persistent.[28] In line with

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[27] The effect on interbank lending rates on impact is considerably stronger after a Federal Reserve monetary policy shock, which foreshadows the financial spillovers from Federal Reserve policy. Over a one-year horizon, however, the effects from the two monetary policy sources are very similar, as shown in appendix A3.

[28] Under the rotational sign restrictions described in Jarociński and Karadi (2020) the US dollar appreciation is persistently statistically significant, but even then it remains smaller for at least one year than the euro appreciation after an ECB tightening.

Itskhoki and Mukhin (2019), pure US monetary policy shocks trigger a weaker US dollar response than typically found in the literature (Miranda-Agrippino and Rey, 2015, Dedola et al., 2017).[29]

4.2.1 Real activity and prices

Our empirical approach suggests that both ECB and Federal Reserve monetary policy have a large impact on domestic consumer price inflation and real activity. Figure 9 shows the domestic effect of an exogenous monetary policy tightening in the respective region as a dotted line. Whenever the domestic effect is statistically significant at the 68% level this is marked by diamonds instead of dots. After an ECB tightening, euro area inflation drops immediately and significantly. The effect of an ECB monetary policy shock on prices is highly persistent, which documents the effectiveness of ECB policy tools. After an exogenous Federal Reserve tightening, the response of US inflation is not statistically significant for our baseline identification scheme. Under the more general rotational sign restrictions approach, however, the effect of Federal Reserve monetary policy on the US consumer prices becomes comparable in size to that of the ECB on euro area prices. Our findings also suggest that the fall in industrial production is statistically significant both after an ECB and after a Federal Reserve tightening – reaching a trough after about 10-20 months. Unemployment also rises in response to an ECB and Federal Reserve monetary policy tightening, albeit that the effect is statistically significant in the latter case only. The more limited impact of ECB monetary policy on unemployment in the euro area is consistent with the higher degree of employment protection in Europe than in the United States.

The evidence shows that monetary policy spillovers to consumer prices are relatively small and short-lived. This can be seen by looking at the solid lines in the top row of Figure 9, showing on the left-hand side the impact of an ECB monetary policy shock on US consumer price index (CPI) and on the right-hand side that of a Federal Reserve monetary policy shock on the euro area harmonised index of consumer prices (HICP). These results show that the impact of a tighter ECB monetary policy on the United States is a marginal decline in the CPI index. This suggests that the negative aggregate demand effect more than offsets the impact of a euro appreciation. This finding is also consistent with anecdotal evidence for an important share of US imports from the euro area being subject to LCP. The spillover from an ECB monetary policy shock to the US is in any case very small compared with the sizeable domestic effect of a Federal Reserve monetary policy shock.

A Federal Reserve monetary policy shock has a somewhat stronger impact on euro area consumer prices in the short term. In particular, there is a statistically significant increase in euro area prices for about one quarter in response to a tighter Federal Reserve monetary policy that may be due to the weakening of the euro. This hypothesis seems corroborated by the fact that the euro area's GDP

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[29] Because the impulse responses reflect the average response of exchange rates during the past 20 years, they wash out atypical responses in special situations, such as the depreciation of the euro after an ECB tightening during the sovereign debt crisis (Rogers et al. 2018). Heterogeneous effects of monetary policy shocks on expectations (Inoue and Rossi, 2019) might explain the difference in the exchange rate impact between ECB and Federal Reserve monetary policy shocks.

deflator,[30] which is not directly exposed to exchange rate changes, does not respond to a Federal Reserve monetary policy shock. The finding of a statistically significant rise in euro area consumer prices in the absence of a corresponding increase in the GDP deflator suggests that a non-trivial component of euro area imports from the United States is priced in US dollars. It is also consistent with prices of euro area imports from non-US sources being sticky in US dollars, i.e. DCP.

Figure 9: Bilateral spillovers from a monetary policy tightening to real activity and prices
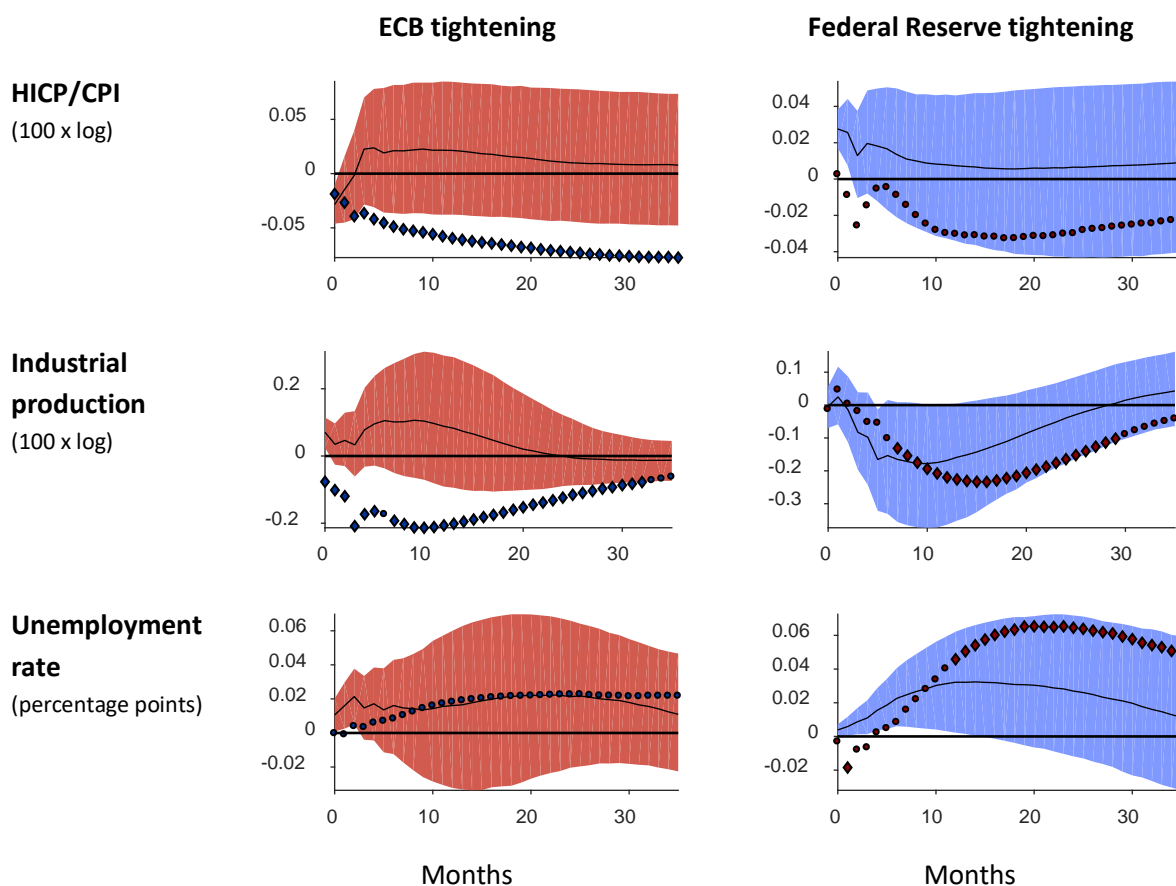
Notes: The solid line plots the median impulse response surrounded by the 68% confidence band. In the left-hand column these are the responses to an ECB tightening, in the right-hand column responses to a Federal Reserve tightening. Quantities for the United States are plotted in red, quantities for the euro area in blue. The dotted lines plot the responses of the corresponding domestic variables, with diamonds symbolising significance at the 68% level. In the left-hand column these are the responses of euro area variables, in the right-hand column the responses of US variables.

Besides these limited short-term spillovers, consumer prices in the euro area and the United States do not respond to monetary policy shocks abroad beyond one quarter. This is an important finding, because the central banks attempt to stabilise inflation and real activity only at medium-term horizons.

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[30] Please refer to appendix A3 for this and more impulse responses.

For example, the ECB's mandate stipulates that it must maintain price stability, which is defined as consumer price inflation of below, but close to, 2% over the medium term.

Our findings suggest that spillovers to unemployment and industrial production are considerable after a Federal Reserve shock, but not after an ECB shock. The impact of an ECB monetary policy shock on US unemployment is not statistically significant beyond one quarter, while the impact on US industrial production is even slightly expansionary. An expansionary spillover from ECB monetary policy tightening to US industrial production may in theory occur under PCP as US producers temporarily gain competiveness relative to their European counterparts. This response is, however, not consistent with economic theory in the more realistic context of US DCP. Looking beyond the one-month horizon, spillovers to US industrial production are short-lived and statistically insignificant. The impact of a Federal Reserve monetary policy tightening on the euro area, however, is sizeable and much longer-lasting. For a full year euro area unemployment and industrial production respond by at least as much as their US counterparts, and initially the response is even larger than the impact in the United States.[31] After one year the increase in the unemployment rate in the euro area is still close to one-half of the domestic increase in the United States.

4.2.2 Trade

The main international transmission channel of monetary policy in textbook models operates via the effect of exchange rates on exports (e.g. Mundell, 1963). In this section we explore the relative importance of the aggregate demand and expenditure-switching effects in transmitting spillovers from monetary policy tightening.

The effect of monetary policy on prices differs between the ECB and the Federal Reserve, but bilateral spillovers to trade volumes are insignificant. The difference reflects the special role of the US dollar and of the euro in trade invoicing.

A monetary policy tightening by either central bank induces an appreciation of the respective real effective exchange rate (Figure 10). However, our estimates suggest that the effect of an ECB monetary policy shock on the euro-dollar exchange rate is larger than that of a Federal Reserve monetary policy shock.[32] Because of the tight trade link between the euro area and the United States, both central banks also affect each other's real exchange rate. A Federal Reserve tightening triggers a persistent and marginally statistically significant depreciation of the euro against a trade-weighted basket of currencies. An ECB tightening leads to a depreciation of the real effective exchange rate of the US dollar for more than one year. Of course, these results are at least in part due to the large weight each currency has in the effective exchange rate of the other.

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[31] The spillover estimate for Federal Reserve shocks is rather conservative. The estimated spillover from Federal Reserve shocks to the euro area based on rotational sign restrictions, which – as noted – capture US monetary policy shocks better, are larger. The back-of-the-envelope computations in Ammer et al. (2016) suggest that the transmission of US monetary policy to foreign real GDP operates predominantly through the financial channel.

[32] The response of exchange rates to Federal Reserve monetary policy shocks is also weaker under rotational sign restrictions.

Figure 10: Response of euro area and US trade to a monetary policy tightening
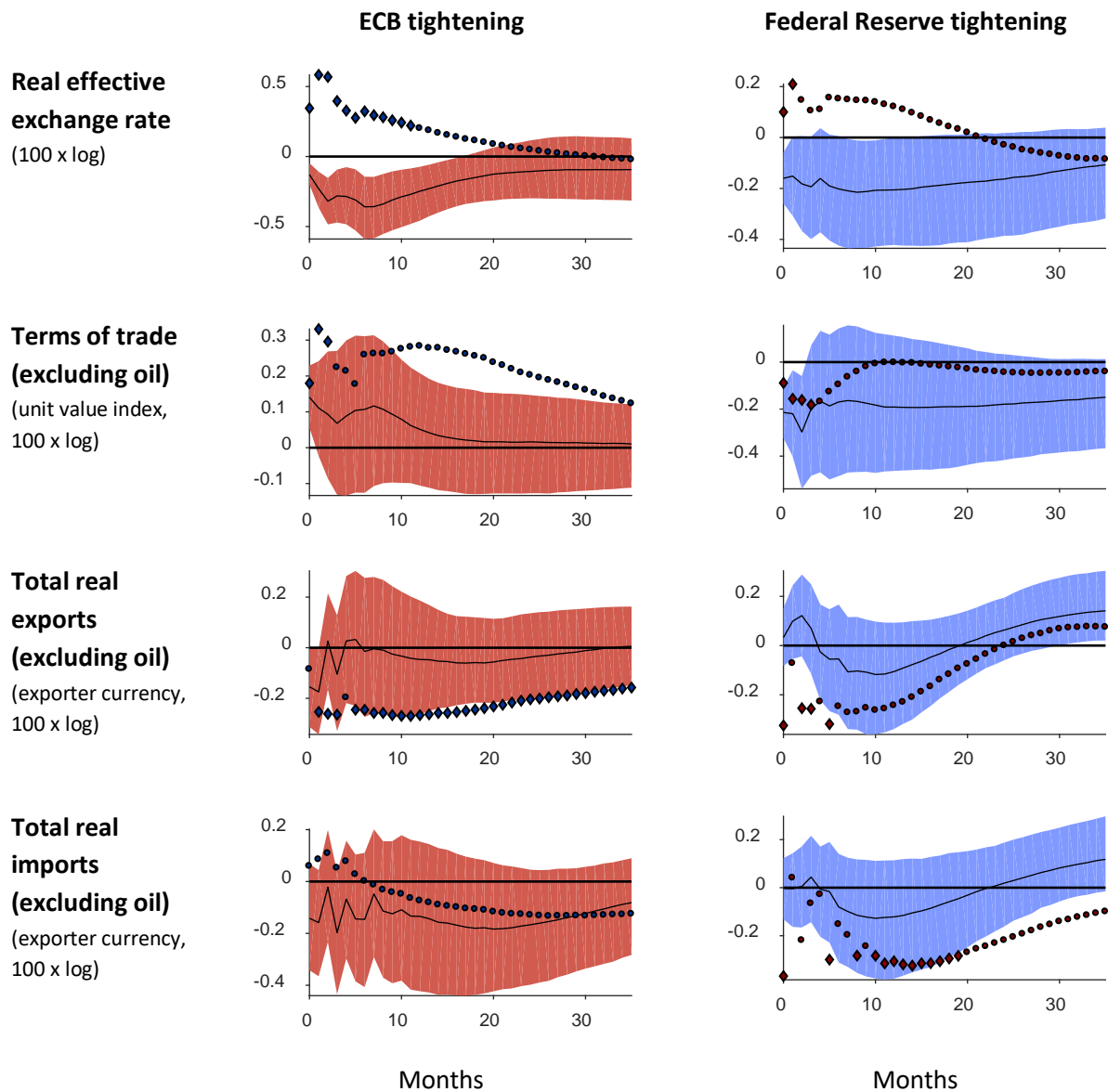
Notes: The left-hand column shows the responses to an ECB tightening, and the right-hand column the responses to a Federal Reserve tightening. Quantities for the United States are plotted in red, quantities for the euro area in blue. The dotted lines are the responses of the domestic variables, with diamonds symbolising significance at the 68% level. In the left-hand column these are the responses of euro area variables, in the right-hand column the responses of US variables. The solid line shows the median impulse response of the corresponding spillover with a 68% confidence band. The real effective exchange rate is the number of trade-weighted foreign currency units per home currency unit. Within any given graph, the dotted line and the solid line therefore differ in their denominator.

The responses of the US terms of trade to ECB and Federal Reserve monetary policy shocks are consistent with dominant-currency pricing. The second row of Figure 10 shows that the US terms of trade vis-à-vis the rest of the world, i.e. the difference between export and import prices excluding oil,

indeed barely respond to Federal Reserve monetary policy. This finding is consistent with US dollar DCP, under which US import and export prices denominated in US dollars do not move on impact as they are sticky in US dollars.[33] Notice that under PCP, i.e. when export prices are sticky in the currency of the producer, a Federal Reserve monetary tightening that leads to a US dollar appreciation would improve the US terms of trade for the reason that US dollar import prices would fall and US dollar export prices remain unchanged in the short term. The US terms of trade are also relatively stable following an ECB monetary policy shock, except for a very small improvement on impact.

The monetary policy of the Federal Reserve has a large impact on both US exports and US imports. On the one hand, the decline in US real exports reflects the expenditure-switching channel: under DCP, i.e. when the prices of US exports to the rest of the world are sticky in US dollars, a Federal Reserve tightening that leads to an appreciation in the US dollar reduces the competitiveness of US exports. On the other hand, the contemporaneous drop in imports is driven by the aggregate demand channel: with import prices sticky in US dollars, there is no expenditure switching that could mitigate the effect of declining US demand on US imports. As a result, US real imports also drop by a statistically significant amount. This is in line with the notion that under PCP US imports should rise through the expenditure-switching channel. There is also no significant impact from a Federal Reserve monetary policy shock on euro area trade, which may be because the United States accounts for only a limited, if important, share of total euro area trade.

Euro area trade appears to conform to the predictions of producer-currency pricing or, alternatively, to a combination of producer-currency pricing for euro area exports and US dollar dominant-currency pricing for imports. An ECB tightening improves the euro area's terms of trade significantly and persistently. This is what PCP predicts, as import prices expressed in euro would fall given the appreciation of the euro, while export prices expressed in euro would remain unchanged. However, this finding is also consistent with euro area export prices being sticky in euro and its import prices in US dollar, i.e. DCP of global exports excluding those of the euro area. After a Federal Reserve tightening, euro area terms of trade deteriorate for several months. This finding is again consistent both with PCP (which is equivalent to DCP for bilateral US exports to the euro area) and, alternatively, with US dollar DCP in global exports excluding those of the euro area. In the data, a large share of euro area imports and exports are invoiced in euro. However, the share of imports invoiced in euro is smaller than the corresponding share of exports (see Figure 6).

ECB monetary policy strongly affects euro area exports, but not imports. Euro area exports decline significantly and permanently after an ECB tightening. The immediacy of this drop is further evidence that a relevant share of euro area export prices is sticky in euro, and hence subject to PCP. Euro area imports do not move much after the ECB monetary policy tightening. This finding is consistent with the hypothesis that the expenditure-switching and aggregate demand channels offset each other. There is

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[33] From the perspective of the United States, DCP is equivalent to PCP in exports and LCP in imports.

also no significant impact of ECB monetary policy on US trade, which is again consistent with DCP in trade with the United States.

Overall, there are no notable spillovers from ECB monetary policy to US trade and from Federal Reserve monetary policy to euro area trade. However, given the evidence for US dollar DCP in global exports excluding those of the euro area, the results so far suggest that in particular Federal Reserve monetary policy may have a large impact on trade of other economies.

4.2.3 Financial conditions

The comparable size of the real economies of the euro area and the United States contrasts sharply with the unequal global importance of their financial sectors. The global dominance of US financial markets renders the financial channel between the United States and the euro area almost unidirectional.

Financial spillovers between the ECB and the Federal Reserve are very asymmetric. Figure 11 shows the spillovers to three financial variables: stock price indices, spreads of speculative-grade corporate bonds, and sovereign bond yields.

For stock prices, bilateral spillovers from both ECB and Federal Reserve monetary policy shocks are negligible. As theory predicts, domestic stock prices decline on impact in response to a monetary policy tightening, especially after a tightening by the Federal Reserve. In contrast, the equity market spillovers are not statistically significant, even on impact. This means that high-frequency correlation between the stock markets on the two sides of the Atlantic after a monetary policy shock may be observed for a couple of days, but tends to fade thereafter and is no longer detectable at monthly frequency.

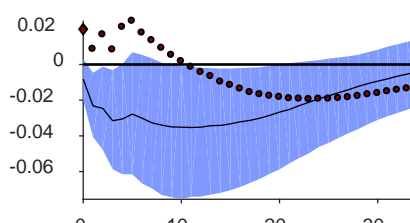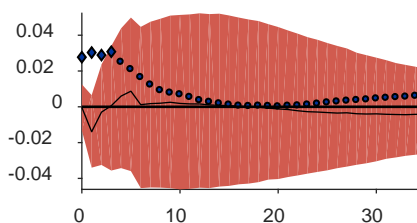**Figure 11: Financial spillovers of a monetary policy tightening**
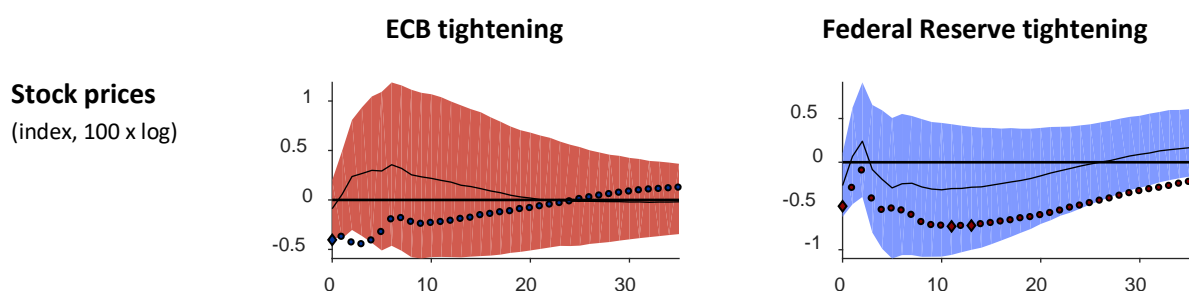
Corporate bond spreads

(below investment grade, all maturities, percentage points)
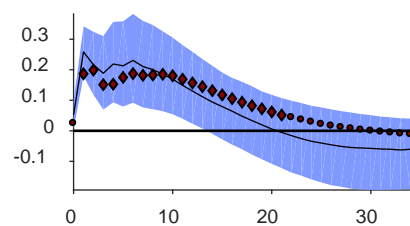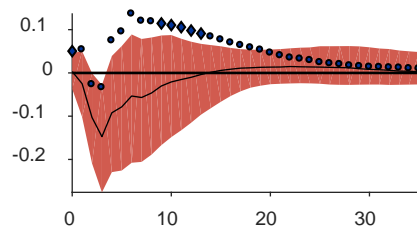
Bond yields

(one-year yield on government bonds, percentage points)

Months   Months

Notes: The left-hand column shows the responses to an ECB tightening, and the right-hand column the responses to a Federal Reserve tightening. Quantities for the United States are plotted in red, quantities of the euro area in blue. The dotted lines are the responses of the domestic variables, with diamonds symbolising significance at the 68% level. In the left-hand column these are the responses of euro area variables, in the right column the responses of US variables. The solid line shows the median impulse response of the corresponding spillover with a 68% confidence band. The stock index shown for the euro area is the Euro Stoxx 50, the index for the United States the S&P 500. The corporate bond spread is the option-adjusted spread between a corporate bond with BBB or below investment grade rating and a government bond. The government bonds used are Bunds for the euro area and Treasuries for the United States.

An important finding of our analysis is that Federal Reserve monetary policy strongly affects financing conditions in the euro area. The second row of Figure 11 shows the option-adjusted spread between a basket of corporate bonds below investment grade (i.e. rated BBB or below) and government bonds. After a Federal Reserve tightening, the figure shows a statistically significant and persistent increase in the spread of speculative-grade corporate bonds in the euro area.[34] In fact this financial spillover is as large as the response of domestic (US) corporate bond spreads, shown by the red dotted line. One-year Bund yields decline after a Federal Reserve tightening,[35] which points to some (systematic) offsetting response by the ECB to mitigate the effects of Federal Reserve monetary policy shocks on the euro area economy.[36] Clearly ECB monetary policy surprises have much weaker financial spillovers than those of Federal Reserve. A corollary of this finding is that the co-movement between euro area and US bond yields typically observed in the data stems from global developments which trigger similar systematic monetary policy responses in both countries (Belke and Gros, 2005). Alternatively, such co-movement

[34] These corporate bonds were not part of the ECB's asset purchase programme. It is conceivable that in recent years they have been more isolated from Federal Reserve monetary policy shocks, but this period is too short to significantly dampen the estimated spillover from monetary policy shocks. The impulse responses show the average spillover over 20 years.

[35] Under rotational sign restrictions, after a Federal Reserve tightening euro area one-year interest rate swaps decline significantly as well.

[36] All euro area impulse responses are net of the effect of this systematic ECB policy response.

could reflect spillovers from central bank information effects (Jarociński and Strasser, 2020).[37] But spillovers from pure monetary policy shocks do not seem to account for the observed co-movement between many financial market variables in the euro area and the United States.

In contrast, an ECB monetary policy tightening does not have a comparable effect on US financial conditions. US corporate bond spreads – unlike euro area corporate bond spreads – do not increase after an ECB tightening. And although one-year government bond yields in the euro area respond significantly to the ECB monetary policy shock, there are no discernible spillovers to US bond yields.[38]

In summary, a monetary policy tightening by the Federal Reserve tightens financial conditions in the euro area but an ECB tightening does not tighten financial conditions in the United States. In Section 5 we explore whether this asymmetry is specific to the euro area-United States pair; or rather we observe a systematic pattern that applies to the global economy as a whole and confers a special role to Federal Reserve monetary policy along the lines of Miranda-Agrippino and Rey (2015).

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[37] Because the effects shown are long-term averages, they are robust to isolated spillover episodes, e.g. in the context of unconventional monetary policy. The period of unconventional monetary policies in the euro area is too short to confirm or reject a possible change in spillovers from the ECB to the United States in recent years. Using a different approach, Curcuru et al. (2018b) find that between the euro area and the United States spillovers of conventional monetary policy (as measured by changes in expected interest rates) on ten-year yields were not significantly different from spillovers of unconventional monetary policy (as measured by changes in term premia).

[38] After both ECB and Federal Reserve monetary policy shocks the respective domestic bond yields respond very similarly on impact. During the first half year after the shock a considerable term spread opens up, as shown in appendix A3. Only thereafter do longer maturities follow short-term rates, as noted by Hanson and Stein (2015).

5. Empirical analysis of the international effects of ECB and Federal Reserve monetary policy shocks

5.1. Global financial markets

Federal Reserve monetary policy drives borrowing denominated in US dollars worldwide (Figure 12). A prominent example is the denomination of new debt issues by borrowers whose business activity is mostly located outside of the United States (and other countries which use the US dollar as their official currency). After a Federal Reserve tightening, new issuance of dollar-denominated syndicated loans outside the United States drops by more than 4%, and new dollar-denominated debt capital, which includes all sectors (government, financial and non-financial) drops by even more. One might conjecture that this drop is mainly due to the financial sector, but this is not the case. Non-financial corporations outside the United States reduce their issuance of dollar bonds by just as much.[39] This reveals a direct link between US financial conditions and investment activity in the rest of the world, i.e. a powerful financial spillover channel from Federal Reserve monetary policy to the rest of the world.

Figure 12: Effects of a monetary policy tightening by the ECB or the Federal Reserve on global financial markets
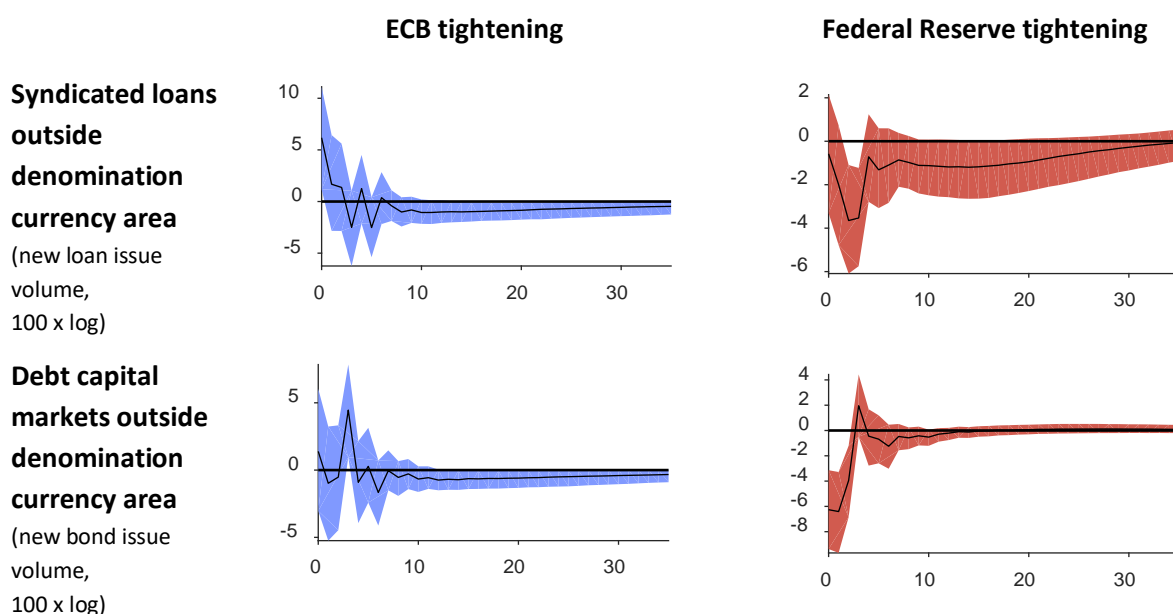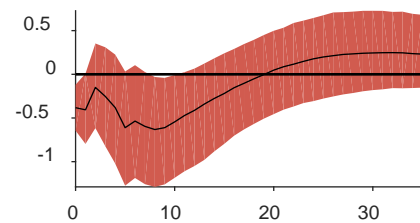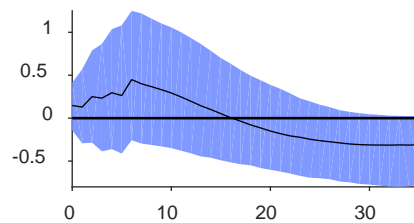

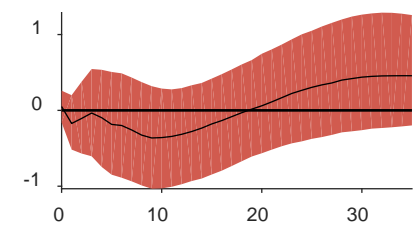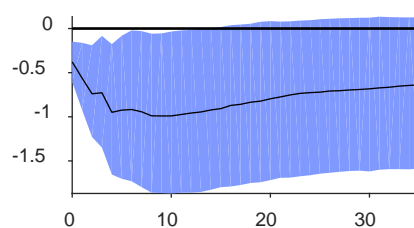[39] Please refer to Appendix A3 for this and further impulse responses.

Portfolio investment
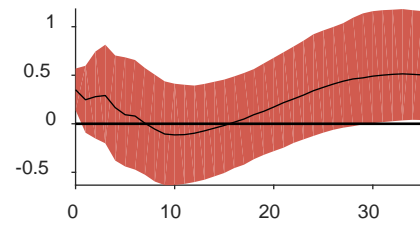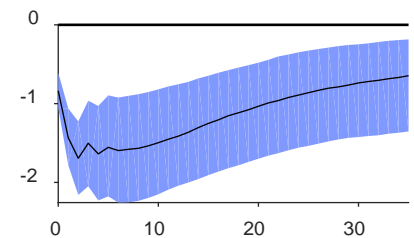(net acquisition of financial assets, percentages of GDP)
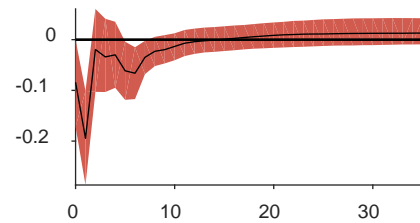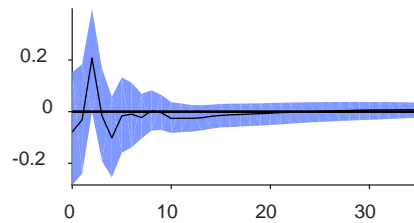
Global stock prices
(MSCI world index excluding United States and euro area, 100 x log)

Commodity prices in US dollars
(index, excluding oil, 100 x log)

Commodity prices in euro
(index, excluding oil, 100 x log)

Months

Notes: The solid line shows the median impulse response surrounded by the 68% confidence band. In the left-hand column these are the responses to an ECB tightening, in the right-hand column the responses to a Federal Reserve tightening. Quantities related to the euro area are plotted in blue, quantities related to the United States in red.

The effect of ECB monetary policy on borrowing in euro outside the euro area is not statistically significant. Euro-denominated borrowing outside the euro area is less common than US dollar-denominated borrowing outside the United States.[40] But even in relative terms the effect of ECB monetary policy on foreign euro borrowing is much smaller and essentially not statistically significant.

Likewise, international portfolio investment drops significantly after a Federal Reserve tightening. The impact of Federal Reserve monetary policy tightening on financial claims of residents of the respective

[40] Since 1999 on average about 31% of US dollar-denominated syndicated loans and about 22% of debt capital have been issued outside the United States, whereas of the corresponding euro-denominated assets only about 4% and 7% respectively have been issued outside the euro area. The volume in these foreign euro-denominated markets over the same period was about one-sixth of that in foreign US dollar-denominated markets for syndicated loans, and one-third in the case of debt capital.

currency area on non-residents is negative and statistically significant, unlike in the case of ECB monetary policy tightening. After a tightening by the Federal Reserve, US residents acquire a significantly smaller amount of foreign financial assets, i.e. claims against non-US residents, in net terms. Since US liabilities in net terms drop simultaneously, cross-border financial investment positions shrink, consistent with the hypothesis of a global financial cycle driven by Federal Reserve monetary policy (Miranda-Agrippino and Rey, 2015; Dées and Galesi, 2019). Again, the analogous effects of ECB monetary policy tightening are not statistically significant.

A Federal Reserve monetary policy tightening also depresses global stock markets, while ECB monetary policy tightening is inconsequential. Global stock prices, summarised by the MSCI index excluding both US and euro area stocks in Figure 12, fall on impact and a few months later (marginally statistically significantly) after a monetary tightening by the Federal Reserve, but remain unchanged after an ECB tightening. It is also worth noting that global stock prices respond more strongly to the Federal Reserve's monetary policy than the euro area stock prices presented earlier.

ECB monetary policy does have a statistically significant impact on non-oil commodity prices, however. Although the spillover from ECB monetary policy via financial conditions is negligible, there is an indirect impact via its impact on euro area business cycle. An ECB monetary policy tightening leads to a drop in non-oil commodity prices quoted in US dollars; the euro appreciation leads to an even larger drop in commodity prices measured in euro. The effect of Federal Reserve monetary policy is statistically significant only under the rotational sign restrictions identification approach.[41]

5.2. Emerging economies

The dominance of Federal Reserve monetary policy spillovers to global financial markets relative to those emitted by the ECB begs the question whether this extends to macroeconomic and financial variables in specific other economies, in particular emerging economies.

Indeed, financial spillovers to emerging economies from Federal Reserve monetary policy are larger than those from ECB monetary policy (Figure 13). After a Federal Reserve monetary policy shock, stock prices in emerging economies drop statistically significantly. After an ECB monetary policy shock, they barely move. This mirrors the strong spillovers of US monetary policy shocks to the financial markets of emerging economies found by Hoek et al. (2019).

The evidence for asymmetric effects of Federal Reserve and ECB monetary policy on emerging economies extends to real GDP. The tightening of both ECB and Federal Reserve monetary policy impacts real GDP growth in emerging economies, but the effect is statistically significant only in case of a Federal Reserve tightening.

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[41] The impact of a Federal Reserve tightening on commodity prices quoted in US dollars under rotational sign restrictions resembles the impact of an ECB tightening shown in Figure 12.

Figure 13: Effects of a monetary policy tightening by the ECB or the Federal Reserve on emerging economies
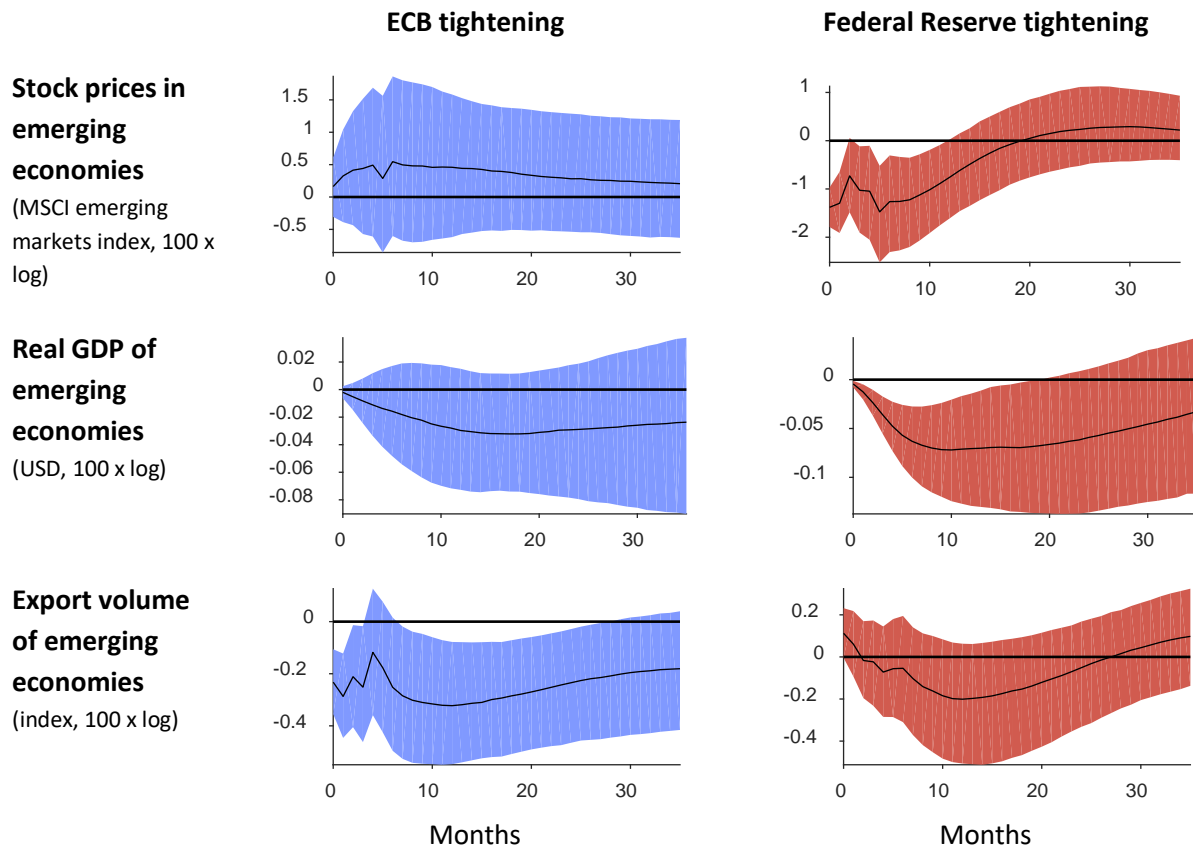
Notes: The solid line shows the median impulse response surrounded by the 68% confidence band. In the left-hand column these are the responses to an ECB tightening, in the right-hand column the responses to a Federal Reserve tightening.

Both the ECB and the Federal Reserve affect trade of emerging economies. After an ECB tightening, exports and imports (including energy) decline persistently. Exports and imports also fall after a Federal Reserve tightening, although the decline in exports is only statistically significant under the rotational sign restrictions approach.[42]

The cross-border impact of ECB/Federal Reserve monetary policy on trade in emerging economies operates through both the expenditure-switching channel and, with some delay, through the aggregate demand channel. To better understand the transmission channel behind the impulse responses, we narrow the analysis down to a smaller set of countries and exclude oil trade.[43] We focus on spillovers to Brazil, Russia, India, China and South Africa, often referred to as "BRICS" countries. After an ECB tightening, euro area non-oil exports to BRICS countries decline persistently. Euro area imports

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[42] Likewise, the remaining four impulse responses to a Federal Reserve shock in Figure 13 are statistically significant (or more precisely estimated) under the rotational sign restrictions approach.

[43] Please refer to Appendix A3 for these impulse responses.

from BRICS decline with a delay, but this decline is not statistically significant. Overall, the effects of monetary policy shocks on trade with the BRICS countries are similar for the Federal Reserve and the ECB. The demand effects that start to dampen imports from BRICS about half a year after the shock are, however, more pronounced for shocks stemming from the Federal Reserve, in line with the stronger impact of Federal Reserve monetary policy on e.g. US unemployment and the weaker appreciation of the US dollar (see Figure 8).

According to these estimates monetary policy decisions in advanced countries could lead to policy trade-offs in emerging economies. The implications of this are, however, not straightforward as these trade-offs could reflect externalities that are not fully internalised but also economic frictions, that would be best addressed locally. Bowman et al. (2015) have shown, for example, that the responsiveness of emerging economies to unconventional monetary policy announcements by the Federal Reserve was very heterogeneous, depending on the economy's current account balance, currency regime, and default risk in its banking system, among other factors.

5.3. Causes of the asymmetric spillovers from ECB and Federal Reserve monetary policy

The direct comparison of ECB and Federal Reserve monetary policy in one coherent framework suggests a pronounced asymmetry in their cross-border effects. Importantly, this asymmetry is confirmed after purging central bank information effects from monetary policy announcement surprises.

Overall, a "hierarchy" of monetary policy spillovers emerges, which places the Federal Reserve ahead of the ECB in terms of the global impact of its policies. Financial spillovers emanating from Federal Reserve monetary policy spread to the euro area and other countries. Trade spillovers emanating from ECB monetary policy barely affect the United States, but do spread to other countries.

The asymmetry of monetary policy spillovers is most prominent in financial channels. This is particularly evident in the strong response of bond spreads to monetary policy shocks. The asymmetry of financial spillovers has been observed previously. Ehrmann et al. (2011), for example, show that US financial markets explain 30% of fluctuations in euro area financial markets, whereas euro area markets account for only 6% of fluctuations in US financial markets. Our results put into perspective the observation of Curcuru et al. (2018a) that during the past 12 years German and US yields were synchronised in the aftermath of monetary policy shocks from either central bank: a broader set of measures of financial conditions, including corporate bond spreads, paints a clear picture of unidirectional financial spillovers from the United States to the euro area. One could argue that not much has changed since the inception of the euro. At that time, Ehrmann and Fratzscher (2003) documented that euro area money markets responded strongly to Federal Reserve announcements, whereas US financial markets in general did not respond to ECB announcements.

At least three well-known factors contribute to the asymmetry of the international impact of ECB and Federal Reserve monetary policy: the central role of US financial markets, the dominant role of the US dollar, and the relatively low trade exposure of the United States.

The first factor is the central role of US financial markets. US financial markets represent a global financial hub, whose size and global interconnectedness can be seen, for example, in the importance of the US dollar lending market, as shown in Section 5.1. The evidence in Section 3.3 suggests that US financial markets have become even more important during the past decade. In fact, it has been argued in this vein that Federal Reserve monetary policy is a major driver of the global financial cycle (Miranda-Agrippino and Rey, 2015).[44]

A second equally important factor is that the US dollar remains the globally dominant currency. A dominant trade invoicing currency changes transmission via the exchange rate competitiveness channel. Our results suggest, however, that the central role of the US dollar in trade invoicing may be only one aspect of dollar dominance. More important is the US dollar's dominance in the pricing of financial assets, which amplifies the exchange rate effect of Federal Reserve monetary policy, affecting financial conditions worldwide.

The third factor which helps explain the asymmetry across the two regions is the stronger importance of trade for euro area GDP than for US GDP. Figures 10 and 13 highlight the pronounced responsiveness of euro area trade to exchange rate movements, especially in trade with emerging economies.

The first two factors contribute to the potential special role of Federal Reserve monetary policy as a driver of the global financial cycle. The global effects of Federal Reserve monetary policy are strong, and are not limited to emerging economies but manifest themselves also in bilateral spillovers to the euro area (see e.g. Figure 11). Further adding to this might be other countries mimicking US policy, which is, however, not separable in our analysis.[45]

The third factor helps explains why spillovers from the ECB tend to transmit mainly via trade channels. These spillovers via trade from the ECB are stronger for other economies than bilaterally with the United States. For trade partners other than the United States, the euro area's trade share is considerable, so that ECB monetary policy can spill over to smaller countries via, specifically, the demand and competitiveness channels.

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[44] For international capital flows, US monetary policy may be less important than financial shocks. Habib and Venditti (2019) find that changes in global risk caused by "pure" financial shocks have an even larger effect on capital flows than US monetary policy shocks.

[45] See Mukhin (2018) as well as Georgiadis and Zhu (2019).

5.4. The consequences of bipolar dominant-currency pricing

From a theoretical perspective, the response of key trade variables to monetary policy shocks depends crucially on the currency in which trade prices are set – and thus sticky in the short term. For example, under DCP, a multilateral appreciation of the non-dominant home currency due to a contractionary home monetary policy shock leaves the home terms of trade stable, as import and export prices both fall in home currency terms. This is in contrast to PCP, under which the terms of trade improve because home import prices fall in home currency terms while home export prices stay the same in that currency. It is also in contrast to LCP, under which the terms of trade deteriorate, as home import prices are constant in home currency terms while home export prices fall in home currency terms. In turn, the different responses of the terms of trade across DCP, PCP and LCP imply a different role for expenditure switching in response to multilateral appreciation of the (non-dominant) home currency, and thus different behaviour of monetary policy spillovers: Under DCP, expenditure switching occurs through home imports alone. Under PCP, by contrast, it occurs through both home imports and exports. Under LCP, expenditure switching is muted.

Dominant-currency pricing has important implications for the role of the US dollar in global trade. In the case of DCP, an across-the-board appreciation of the dominant currency, say the US dollar, driven for example by a contractionary Federal Reserve monetary policy shock, reduces imports and exports globally, even for transactions that do not involve the United States. Specifically, because also prices of non-US imports are sticky in US dollars, depreciation against the US dollar triggers expenditure switching away from imports towards domestically produced goods. As a mirror image, because prices of non-US exports are sticky in US dollars, depreciation against the US dollar lowers exports of all countries. Because a multilateral appreciation of the US dollar reduces both exports and imports even for transactions that do not involve the United States, global trade is reduced more strongly under DCP than under PCP or LCP.

We illustrate the effects of different pricing paradigms on spillovers from monetary policy shocks using the ECB's multi-country model, known as ECB-Global.[46] The model follows a semi-structural approach in order to combine the advantages of fully structural models and of those composed of reduced-form equations. It includes the euro area, the United States, Japan, the United Kingdom, China, the rest of emerging Asia, oil-producing economies and the rest of the world. The evolution of the economies in ECB-Global is first determined by a set of core structural relationships (e.g. Phillips and investment-saving curves), giving the shocks a clean economic interpretation and facilitating the tracking of the domestic and international transmission of shocks. Second, reduced-form equations are added to enrich the core of ECB-Global. This reduced-form aspect makes it easier to modify the model in a flexible manner, thus improving its empirical fit.

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[46] See Dieppe et al. (2017) and Georgiadis and Mösle (2019) for more details.

In order to illustrate the implications of the special role of the US dollar in trade for spillovers, the baseline version of ECB-Global is modified to incorporate dominant-currency pricing. In particular, we assume that a share of an economy's exports is priced and sticky in US dollar, consistent with the data from Gopinath (2015) displayed in Figure 5, rather than entirely in the exporter's currency (as it would be under PCP). Here we do not consider the counterfactual case of *full* DCP, in which all exports and imports are priced in the dominant currency, as considered by Gopinath et al. (2020). Instead, following the data, we consider a scenario of partial DCP in which only a part of exports and imports is priced in US dollars, and these shares of exports and imports may differ from country to country (see Georgiadis and Schumann, 2019). In general, the share of exports that are invoiced in US dollars is higher for emerging economies than for advanced economies.

Output and trade spillovers from a contractionary Federal Reserve monetary policy shock to the euro area and especially emerging economies are amplified under dominant-currency pricing relative to producer-currency pricing (right-hand panels in Figure 14). Under PCP, total exports from the United States fall by more than 0.4% as the multilateral US dollar appreciation resulting from the tightening in Federal Reserve monetary policy induces expenditure switching away from US-produced goods and towards domestically produced goods in the rest of the world. This drop in US exports is amplified by declining demand in the rest of the world that results from the negative output spillovers from the Federal Reserve monetary policy shock. US imports are relatively stable, falling only by 0.04%, as the expenditure switching in the United States towards imports induced by the appreciation of the US dollar is roughly compensated by the decline in US demand stemming from the contraction in real GDP. In the case of DCP, when prices of traded goods are sticky in US dollars, US imports fall much more strongly, as there is no expenditure switching away from domestically produced goods which could offset the drop in demand for imports due to the decline in real GDP. Overall, US real GDP falls by about 0.3% in response to the Federal Reserve monetary policy tightening. As regards the spillovers through trade under PCP, euro area and emerging market economy exports fall in response to the monetary policy contraction in the United States. However, this fall is confined to a decline in exports to the US, consistent with the fall in US imports, and given the limited share of the euro area's and emerging economies' exports that are destined for the United States, the drop in total exports is limited. The drop in imports is somewhat more pronounced, which is due to oil prices in ECB-Global being assumed to be (somewhat) sticky in US dollars even in the PCP specification of the model. Overall, given the limited trade effects, the spillovers to real GDP in the euro area and emerging market economies are muted under PCP. In the case of DCP, the spillovers to real GDP, in particular in emerging market economies, are amplified, rising from 0.02% under PCP to more than 0.1% under DCP. This is due to a much stronger drop in emerging market economies' exports, which, in turn, is due to the prices of the euro area's and emerging market economies' exports – even to non-US destinations – being sticky in US dollars and hence rising in terms of the importers' currency in response to the appreciation of the US dollar. Because the share of exports priced in US dollars is larger for emerging market economies than for the euro area, the decline in the former's exports is amplified more under DCP.

Figure 14: Spillovers from a contractionary monetary policy shocks in ECB-Global
(percentage deviations from the baseline, average response over four quarters after shock)
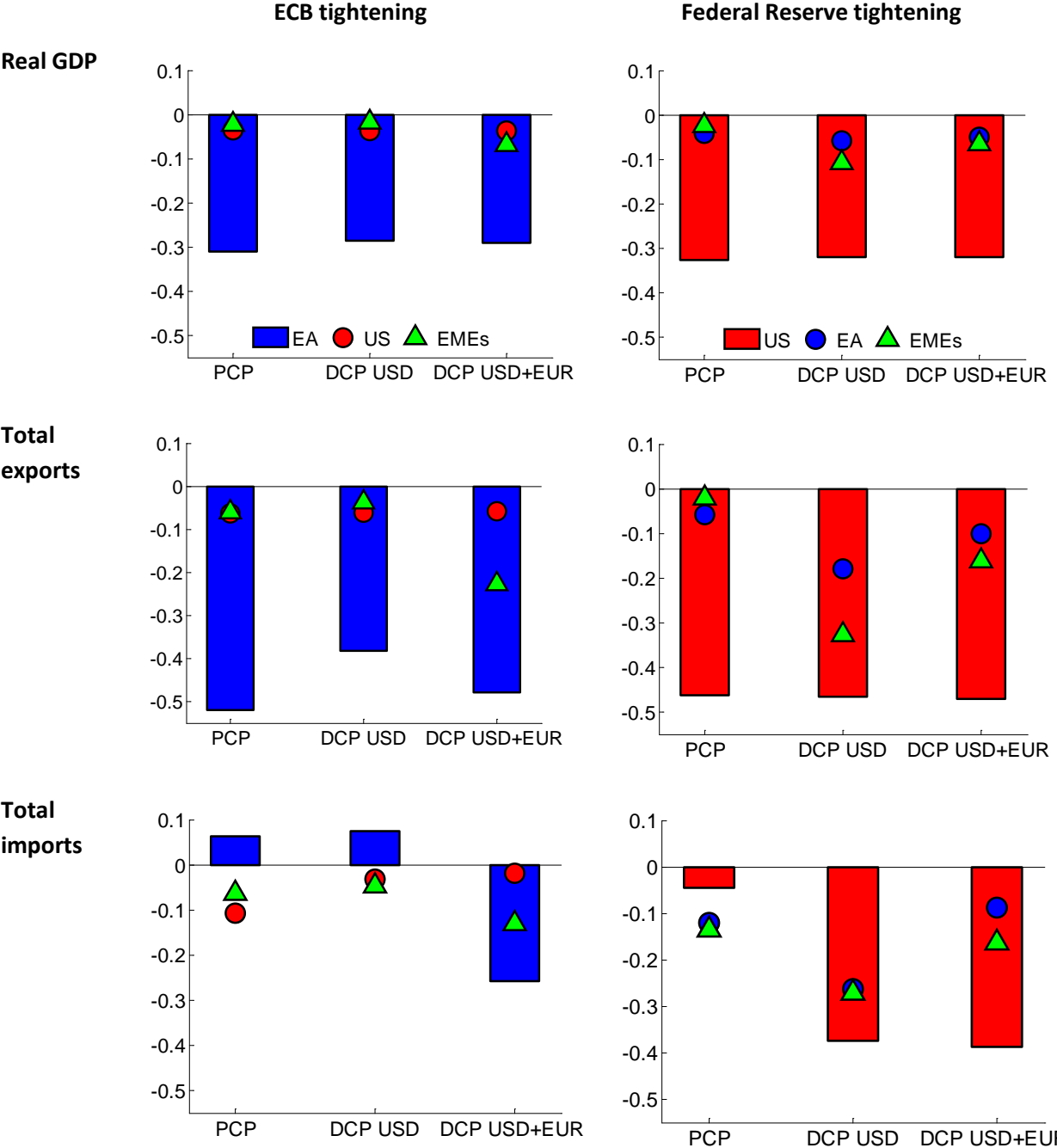
(EA = euro area, US = United States, EMEs = emerging economies)
Source: ECB calculations.

Because the dominant currency in global trade is the US dollar, domestic effects and spillovers from a euro area monetary policy shock hardly change under dominant-currency pricing relative to producer-currency pricing, as shown in the left-hand panels of Figure 14. The tightening of euro area monetary policy leads to an appreciation of the euro against all other currencies. Because a non-trivial share of the prices of the euro area's trade continues to be sticky in euro in the DCP specification of ECB-Global, expenditure switching still induces a fall in euro area exports. The rise in euro area imports is very similar under DCP and PCP, as the euro appreciates against all currencies in response to the domestic monetary policy tightening, including against the US dollar.

The set-up in ECB-Global allows us to simulate the implications of a transition from a configuration with a single dominant currency, i.e. the US dollar, to one in which the euro gains importance in global trade. For the simulation of this US dollar/euro scenario in ECB-Global we distribute the data-based US dollar invoicing shares symmetrically between the US dollar and the euro for all countries. For example, we assume that in emerging market economies, where in the baseline US dollar DCP scenario around 85% of exports are invoiced in US dollar, 42.5% of exports are invoiced in US dollar and 42.5% in euro. The remaining export prices continue to be sticky in the producer's currency as in the baseline US dollar DCP scenario. We also continue to assume that countries price all their exports in US dollars when trading with the US; correspondingly, we now assume that countries price their exports in euro when trading with the euro area. Moreover, we continue to assume that all countries price the same shares of their exports in US dollars and euro, respectively, across all other destinations. Finally, we assume that prices of trade between the United States and the euro area are sticky in US dollars.

In this counterfactual scenario in which the euro becomes a second dominant currency in global trade, the spillovers from euro area monetary policy increase while those from the United States are dampened. In particular, a contractionary euro area monetary policy shock reduces emerging market economies' exports by more than 0.2% and imports by more than 0.1%. Both imports and exports of emerging market economies fall more strongly than under PCP (0.07% and 0.06%) and US dollar DCP (0.05% and 0.04%). The reason is that under US dollar/euro DCP, a part of global trade prices is sticky in euro. As a result, imports become more expensive in local-currency terms in response to the multilateral appreciation of the euro for all economies other than the United States. The implications are again particularly important for trade and real activity in emerging market economies, since that country group prices the largest share of exports in euro.

6. Conclusion and implications for international cooperation

6.1. Monetary policy trade-offs and implications for ECB monetary policy

For policy coordination purposes, spillovers are not the same as externalities. As emphasised, for example, in Claessens et al. (2016), spillovers suggest a need to coordinate policies only if domestic policymakers cannot react to and fully undo the effect of a foreign shock without cost. As this is unlikely to be strictly the case, the (empirical) question is how much reality deviates from this benchmark. The question includes not only to what extent central banks are able to cushion the effects of foreign shocks, but also whether foreign shocks create trade-offs that make domestic monetary policy more complicated or undermine the scope for attaining domestic policy objectives. Such trade-offs are an issue not only for smaller economies, but even for the United States (Obstfeld, 2019).

As shown earlier, Federal Reserve monetary policy spillovers on euro area activity and prices are small but are statistically significant on unemployment. While the ECB and the Federal Reserve might offset inflation and output spillovers, if necessary, the strong responsiveness of euro area financial conditions to Federal Reserve monetary policy shocks could imply a greater scope for macroprudential policies in the euro area (Rey 2016).

The ECB could face trade-offs between price stability on the one hand, and stabilisation of output and financial conditions on the other, if it tried to offset the effects of the spillovers more aggressively than it has done in the past, according to the above VAR estimates. Euro area financial variables, and to some extent unemployment, react more strongly than prices to Federal Reserve monetary shocks. This evidence is consistent with the ECB being, in line with its mandate, focused on achieving price stability over the medium term and not leaning decisively against the Federal Reserve monetary policy spillovers on financial variables or economic activity.

But it seems unlikely that there would be large gains from increasing monetary policy cooperation between the ECB and the Federal Reserve. Monetary policy spillovers between the two currency blocs are small and/or imprecisely estimated. It is not evident that the ECB should be concerned about the response of euro area financial conditions to Federal Reserve monetary policy shocks, as they do not appear to cause a large real spillover. These considerations are the framework which any discussion of the desirability of (a closer) monetary policy cooperation between the ECB and the Federal Reserve must factor in.

6.2. Implications for international policy cooperation

In a broad sense, there is in normal times already a considerable degree of coordination across central banks.[47] For example, central banks around the world tend to use similar policy instruments, and largely agree on some codes of conduct, such as the undesirability of competitive devaluations.

Economic theory tends to advocate more policy coordination in response to globalisation (Engel, 2016a). But this result is highly sensitive to the underlying modelling assumptions (Banerjee et al., 2016; Corsetti and Pesenti, 2005; Dedola et al., 2013; Ostry and Ghosh, 2016; Taylor, 2013), rendering this literature inconclusive at this time.

In practice, international policy coordination, going beyond impromptu coordinated actions, is inherently difficult. Long-term, formalised policy coordination would have to reconcile very heterogeneous views on the shape of the optimal global policy function across different constituencies. Disagreement might originate not only in the political economy – stemming from differences in domestic mandates (Lane, 2019) and the institutional set-up – but also simply in model and parameter uncertainty (Cœuré, 2016). *Formal* international policy coordination is thus unlikely to arise, even in presence of large cross-country spillovers and policy trade-offs.

Because spillovers from ECB monetary policy to the United States do not represent an externality, there is no case for constraining ECB monetary policy. A key conclusion of the empirical analysis in this paper is that ECB monetary policy has only small effects on the US economy. This can have two reasons, which are observationally equivalent in our analysis. First, it might imply that the Federal Reserve has been able and determined to fully offset spillovers from ECB monetary policy. Or, second, it might imply that the ECB monetary policy has not created economically significant spillovers to the United States in the first place. The truth may be a mix of the two: spillovers from the euro area to the United States may be relatively small and not imply relevant policy trade-offs, which means that Federal Reserve can easily tackle them.

Despite the large spillovers from Federal Reserve monetary policy to the global economy, spillovers to the euro area are very limited, again suggesting there is no case for bilateral policy coordination. While our estimates indicate a small spillover to euro area inflation, it seems to be a transitory effect. It hence does not compromise the ECB's mandate to maintain price stability in the medium term. Moreover, given that we find some systematic ECB response to Federal Reserve monetary policy shocks (Figure 11), our results suggest that the ECB is offsetting spillovers without facing meaningful trade-offs.

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[47] The Bretton-Woods system of fixed exchange rates had enforced tight policy coordination. The end of de-facto exchange rate pegs reduced the incentive to consider the foreign effects of domestic monetary policy decisions, until the increasing integration of the world economy rekindled the interest in coordination. For a history of policy coordination, including earlier periods, see e.g. Eichengreen (2013), James (1996), Kahn and Meade (2018), and Webb (1995). Mohan and Kapur (2014) describe monetary policy coordination since the global financial crisis in more detail.

Despite the weak case for monetary policy coordination in normal times, room for coordination might exist in case of large shocks. In particular in periods of financial stress and funding crises in the banking sector, and of strong cross-country connectedness (Diebold and Yilmaz, 2015), the gains from international policy coordination can be large. If, for example, such extreme events triggered a large ECB policy response, our finding of no spillover to the United States might no longer be applicable, because the results of our analysis are based primarily on small policy surprises. The crises and policy responses of the past ten years highlight the fact that the "plausible circumstances" (Obstfeld and Rogoff, 2002) which render domestically optimal policies also globally optimal cannot be taken for granted at all times.

The recent history of ECB-Federal Reserve policy interaction supports this view. Whereas both central banks operate under purely domestic mandates, they have taken joint policy action in the past on an ad hoc basis (Lane, 2019). This was always in response to an exceptional situation and when facing large, common shocks. Under such circumstances, the ECB and the Federal Reserve have announced a policy change on the same day.[48]

In crisis times, coordinated policy action can serve as a communication device to resolve uncertainty quickly. A joint reaction by the ECB and the Federal Reserve to a common shock, as during the global financial crisis, might help to maximise the market impact of monetary policy. Coenen et al. (2017) highlight the importance of clear and effective central bank communication, especially during unconventional times and in the case of rapid shifts in the monetary policy stance. Coordination during crisis times thus goes beyond the classic coordination arrangement which induces central banks to internalise externalities: it is a powerful communication device.

The ECB and the Federal Reserve have formalised their cooperation in providing international liquidity. After a long sequence of temporary bilateral currency swap arrangements from December 2007, they agreed on a standing arrangement in 2013.[49] The timing of these temporary arrangements was not always as tightly synchronised as in the examples listed in the Appendix. For example, the Federal Reserve swap line announcement on the morning of 9 May 2010 was followed by the corresponding ECB announcement one day later. But in such press releases both the ECB and the Federal Reserve often stressed that central banks "work together closely", and the ECB mentioned international coordination (of liquidity provision) and cooperation (in swap lines).

Formal ex ante agreements on coordination in extreme events, such as swap lines, can affect investment incentives in normal times. The analysis of Bahaj and Reis (2018), for example, stresses that swap lines change international portfolio allocations and bank funding costs by lowering the cost of a funding crisis, even when they are not drawn on. Bahaj and Reis find empirical evidence that cheaper US dollar swap lines trigger a shift of funds into US dollar bonds. Thus even though coordination

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[48] Appendix A4 shows the six most prominent instances of the ECB and the Federal Reserve announcing a policy change on the same day.

[49] Bahaj and Reis (2018) argue that such swap lines have by now become an integral part of the global financial safety net. But despite being standing arrangements, the swap lines have to be renewed annually, most recently in May 2019.

agreements are contingent on extreme situations, they also affect economic outcomes in normal times. Formalising coordination for extreme events ex ante needs to take into account such instantaneous effects.[50]

Overall, there appears to be very limited scope for monetary policy coordination between the ECB and the Federal Reserve in normal times, although quick coordinated action might be helpful in times of global crisis.[51] Nurturing the willingness and readiness for policy coordination in the event of a crisis requires an ongoing dialogue in normal times. Even if for good reasons a contingency plan for coordinated action in a crisis is never formalised, the design and activation of coordinated action should be part of a continuous exchange between the ECB and the Federal Reserve.

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[50] Bahaj and Reis (2018) note that the welfare effects of swap lines in normal times, in particular the effects of high levels of foreign funds in US markets and of increased reliance of European banks on US funding, are an open question for research.

[51] Nevertheless, there are good reasons for coordinating macroprudential policy in normal times to avoid crises in the first place. Domestic financial stability benefits from the joint creation of a global financial safety net through proper financial regulation and supervision. Macroprudential coordination is beyond the scope of this paper, however.

7. References

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A. Appendix

A1. Methodology

High-frequency identification of monetary policy shocks

As highlighted in Section 4.1, we use financial market reactions to monetary policy announcements in order to identify monetary policy shocks. The approach follows Jarociński and Karadi (2020).

The dataset consists of 248 Federal Reserve monetary policy announcements since 1990 and 283 ECB monetary policy announcements since 1999. Financial market reactions are measured in the time window starting 10 minutes before and ending 20 minutes after a central bank announcement. In the case of the Federal Reserve, the announcement time is typically the release time of the press release. In the case of the ECB, the time window is longer and ends 20 minutes after the end of the press conference (when there is one). In these windows we record interest rate surprises and stock price surprises. The Federal Reserve interest rate surprises are defined as the mean of the changes in federal funds futures and eurodollar futures with remaining maturities from one month up to one year. The ECB interest rate surprises defined as the mean of the changes in EONIA swaps with maturities from one month up to one year. By including maturities up to one year, these surprises capture not just the changes of the current policy rates but also of the expectations for interest rates up to one year into the future, reflecting forward guidance and non-standard policies. The Federal Reserve stock price surprises are measured as the change in the S&P 500 stock index and the ECB stock price surprises are measured as the change in the Euro Stoxx 50 stock index.

In the next step we isolate the monetary policy shocks from among the interest rate surprises by purging the information effects from them. This is based on the sign restriction: interest rates and stock prices are assumed to co-move negatively after a monetary policy shock, as is implied by a wide range of models. Therefore we treat as monetary policy shocks only those interest rate surprises which co-move negatively with stock prices in the respective month. A more sophisticated alternative is to decompose interest rate and stock price surprises into two orthogonal components and "rotate" them so that one is associated with a negative co-movement and the other with the positive co-movement of interest rate and stock price surprises. Jarociński and Karadi (2020) find that in the large sample for the United States the two approaches yield similar results, but in the euro area sample the former, simpler approach, dubbed "poor man's sign restrictions", yields a stronger instrument for monetary policy (i.e. is associated with a stronger increase in the one-year bond yield) than the more sophisticated sign restrictions approach. Therefore we use this approach for both the United States and the euro area for comparability. The Federal Reserve monetary policy surprise in April 2001 is larger than six standard deviations of monetary policy shocks. We exclude this stark outlier from the analysis.

Estimation of the impulse responses

We track the responses of the economy to the identified shocks using a VAR. The baseline VAR for each country includes the one-year government bond yield, stock prices, the corporate bond spread, industrial production and the respective consumer price index (CPI/HICP). We add the identified shock to this VAR as the first variable. We restrict the coefficients of the first equation to zero, reflecting the fact that the shock is independently and identically distributed. After estimating the VAR with the standard Minnesota prior, we compute the impulse responses to the first shock identified recursively. The variables and the estimation of the baseline VAR are the same as in Jarociński and Karadi (2020). This paper also provides details on the rotational sign restrictions approach, which yields a stronger instrument for Federal Reserve monetary policy shocks, but not for ECB shocks.

We compute the effect of the Federal Reserve policies on the euro area (plotted in the graphs as solid line) by combining the Federal Reserve shocks with the euro area variables in the VAR. Analogously, for the domestic effects of the Federal Reserve policies (plotted with dots) we combine Federal Reserve shocks with the US variables in the VAR. To obtain the effect of the ECB policies, the set-up is simply mirror-inverted: the domestic effect of ECB policies is based on the effect of ECB shocks on euro area variables; the spillover effect to the United States is based on the effect of ECB shocks on US variables. The responses of other variables, which are not part of the baseline VAR specification, are computed by adding them one by one as last variable to the respective baseline VAR.

Several variables that we study are bilateral: the exchange rate, the spread between the United States and the euro area bond, etc. In these cases, we use a bilateral VAR specification[52] to compute their impulse responses. The bilateral VAR includes the exchange rate, the spread between US Treasuries and one-year Bund yields, the corporate bond spread of the country experiencing the shock and, separately for the United States and the euro area, industrial production and consumer price indices.

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[52] Georgiadis, Georgios (2017) compares the performance of bilateral VARs with multilateral (global) VARs.

A2. Data

The monetary and central bank information shocks are part of the online appendix to Jarociński and Karadi (2020).

All series cover the period January 1999-December 2018, unless otherwise noted.

Table A1: Variable descriptions

Variable	Euro area	United States
Interest rate differential	Yield spread between the one-year Bund and the benchmark one-year Treasury as calculated by Thomson Reuters, end-of-month. Source: Thomson Reuters.	Yield spread between the benchmark one-year Treasury and the one-year Bund as calculated by Thomson Reuters, end-of-month. Source: Thomson Reuters.
Exchange rates	ECB reference USD/EUR exchange rate, rebased to EUR/USD, monthly average. Source: ECB Statistical Data Warehouse (SDW).	ECB USD/EUR reference exchange rate, monthly average. Source: SDW.
HICP/CPI	Harmonised Index of Consumer Prices (HICP) for the euro area in changing composition, working-day and seasonally adjusted, monthly. Source: SDW.	Consumer Price Index (CPI) for all urban customers: all Items, seasonally adjusted, monthly. Source: Federal Reserve Bank of St. Louis (FRED database).
Industrial production	Industrial production index, excluding construction, monthly. Source: SDW.	Industrial production index, excluding construction, monthly. Source: FRED.
Unemployment rate	Standardised unemployment rate for euro area in fixed composition (19 countries), seasonally but not working-day adjusted, monthly. Source: SDW.	Civilian unemployment rate, seasonally adjusted, monthly. Source: FRED.
Real effective exchange rate	Real broad effective exchange rate of the euro area, trade-weighted, deflated by relative consumer prices, as calculated by the Bank for International Settlements, monthly. Source: Haver Analytics	Real broad effective exchange rate of the United States, trade-weighted, deflated by relative consumer prices, as calculated by Bank for International Settlements, monthly. Source: Haver Analytics.
Terms of trade (excluding oil)	Export prices over import prices in euro, unit value index, monthly, sample: 2000-2018. Source: Haver Analytics.	Export prices over import prices in US dollars, unit value index, monthly, sample: 2000-2018. Source: Haver Analytics.

Total real exports (excluding oil)	Euro area trade data, deflated by price indicators, excluding oil trade, monthly, sample: 2000-2018. Sources: Haver Analytics, ECB calculations.	US trade data, deflated by price indicators, excluding oil trade, monthly, sample: 2000-2018. Sources: Haver Analytics, ECB calculations.
Total real imports (excluding oil)	Euro area trade data, deflated by price indicators, excluding oil trade, monthly, sample: 2000-2018. Sources: Haver Analytics, ECB calculations.	US trade data, deflated by price indicators, excluding oil trade, monthly, sample: 2000-2018. Sources: Haver Analytics, ECB calculations.
Stock prices	Dow Jones Euro Stoxx 50, historical close, end-of-month. Source: SDW.	S&P Dow Jones S&P 500 index, end-of-month. Source: SDW
Corporate bond spreads	Average spread between euro area corporate bonds and euro area government bonds; ICE BofAML Euro High Yield Index option-adjusted spread, basket of corporate bonds below investment grade (i.e. rated BBB or below), spreads averaged across maturities, monthly average. Source: FRED	Average spread between US corporate bonds and US government bonds; ICE BofAML US High Yield Master II option-adjusted spread, basket of corporate bonds below investment grade (i.e. rated BBB or below), spreads averaged across maturities, monthly average. Source: FRED.
Bond yields	Thomson Reuters benchmark one-year German government bond bid yield, end-of-month. Source: Thomson Reuters.	Thomson Reuters benchmark one-year Treasury bid yield, end-of-month. Source: Thomson Reuters.
Syndicated loans outside denomination currency area	Volume of syndicated loans denominated in euro (or the former currency of one of the 11 initial euro area countries) and newly issued outside of countries with the euro as official currency (pre-1999: outside of the 11 initial member countries), monthly, unit: euro. Sources: Dealogic, ECB calculations.	Volume of syndicated loans denominated in US dollars and newly issued outside of countries with the US dollar as official currency, unit: US dollar, monthly; Sources: Dealogic, ECB calculations.

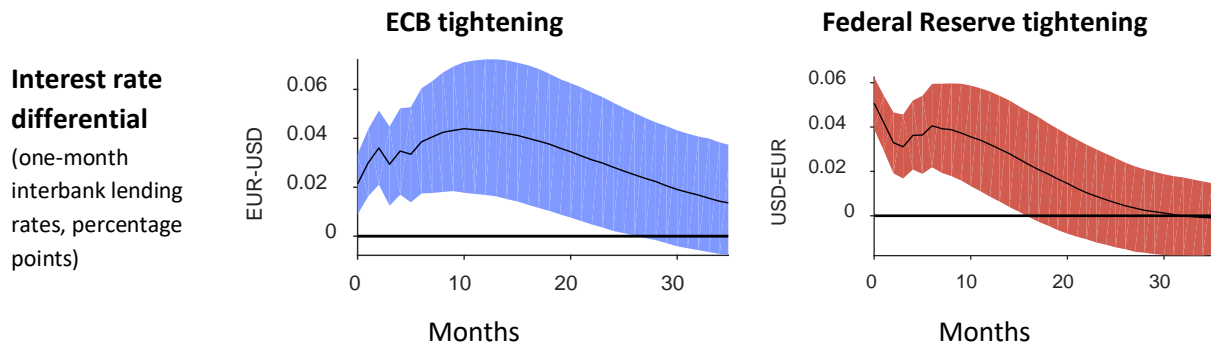|		
Debt capital markets outside denomination currency area	Volume of newly issued debt capital denominated in euro (or the former currency of one of the 11 initial member countries) outside of countries with the euro as official currency (pre-1999: outside of the 11 initial member countries), unit: euro, monthly. Sources: Dealogic, ECB calculations.	Volume of newly issued debt capital denominated in US dollars outside of countries with the US dollar as official currency, unit: US dollar, monthly. Sources: Dealogic, ECB calculations.
Portfolio investment – financial assets	Net acquisition of financial assets, euro area in fixed composition (19 countries) vis-à-vis rest of the world, not seasonally adjusted, monthly, at market value. Source: SDW (balance of payments and international investment position).	Net purchases of foreign securities by US residents, not seasonally adjusted, monthly, at market value. Sources: Treasury International Capital (TIC) Data, Haver Analytics.
Global stock prices	Weighted average of MSCI country indices underlying the MSCI World and MSCI emerging markets indices excluding the United States and the euro area, local currency, all series rebased to 100 in January 2010, countries weighted by market capitalisation in US dollar, end-of-month. Source: Bloomberg, ECB calculations.	
Commodity prices in US dollars	Market prices of raw materials, excluding energy, in US dollars, monthly average. Source: OECD.	
Commodity prices in euro	Market prices of raw materials, excluding energy, in euro, monthly average. Source: OECD.	
Stock prices in emerging economies	MSCI emerging markets index, US dollar, end-of-month. Source: Bloomberg.	
Real GDP of emerging economies	GDP at prices and exchange rates in 2010, seasonally adjusted, in US dollars, cubic spline interpolation from quarterly data, sum of the following countries: Bolivia, Botswana, Brazil, Chile, China, Costa Rica, Ecuador, El Salvador, Hong Kong, India, Indonesia, Israel, Jordan, Kazakhstan, South Korea, Malaysia, Mexico, Paraguay, Peru, Philippines, Poland, Russia, Singapore, South Africa, Taiwan, Thailand, Turkey, Uruguay. Source: Haver Analytics.	
Export volume of emerging economies	Export volume index including energy, 43 countries, monthly. Sources: Haver Analytics and CPB Netherlands Bureau for Economic Policy Analysis World Trade Monitor.	

Table A2: Description of additional variables used in appendix A3

Variable	Euro area	United States
Interest rate differential	Spread between one-month EURIBOR and LIBOR, end-of-month. Source: SDW.	Spread between one-month LIBOR and EURIBOR, end-of-month. Source: FRED.
Core HICP/CPI	HICP for all items excluding energy and food, for euro area in changing composition, working-day and seasonally adjusted, monthly. Source: SDW.	CPI for all urban customers, all items less food and energy in US city average, seasonally adjusted, monthly. Source: FRED.
GDP deflator	GDP deflator interpolated from quarterly data, employing a similar strategy as for the United States. Source: SDW.	GDP deflator interpolated from quarterly data, following Stock and Watson (2010). Source: FRED.
Real GDP	Real GDP interpolated from quarterly data, employing a similar strategy as for the United States. Source: SDW.	Real GDP interpolated from quarterly data, following Stock and Watson (2010). Source: FRED.
Total real trade balance (excluding oil)	Euro area trade data, deflated by price indicators, excluding oil trade, monthly, sample: 2000-2018. Source: Haver Analytics, ECB calculations.	US trade data, deflated by price indicators, excluding oil trade, monthly, sample: 2000-2018. Source: Haver Analytics, ECB calculations.
Interest rate swaps	One-year interest rate swap based on six-month EURIBOR, monthly average. Source: Bloomberg.	One-year interest rate swap based on three-month LIBOR, monthly average. Source: Bloomberg.
Term spreads	Spread between ten and one-year yields based on the estimated German government debt yield curve, end-of-month. Source: Thomson Reuters.	Spread between ten and one-year Treasury constant maturity rates, end-of-month. Source: Thomson Reuters.

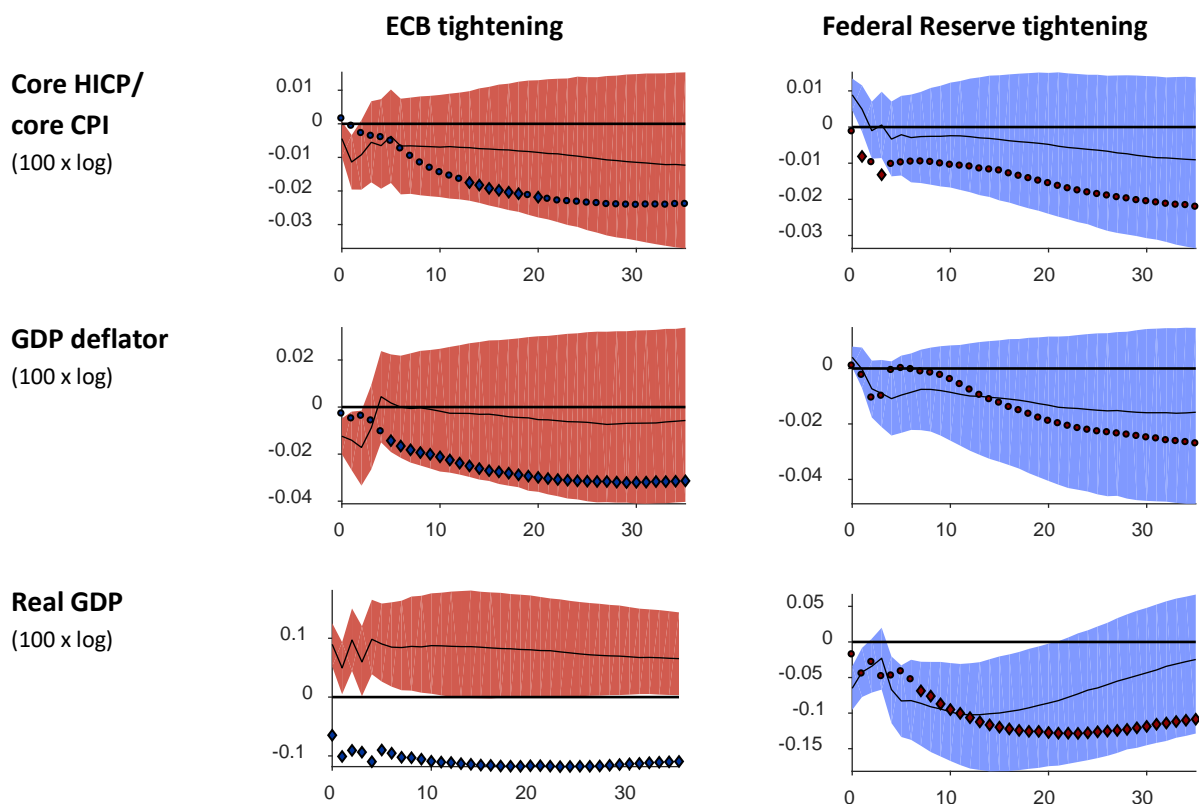| New issuance of bonds outside denomination currency area by non-financial corporations	Volume of debt capital denominated in euro (or the former currency of one of the 11 initial euro area countries) and newly issued outside of countries with the euro as official currency (pre-1999: outside of the initial member countries), non-financial corporations only, monthly, unit: euro. Sources: Dealogic, ECB calculations.	Volume of debt capital denominated in US dollars and newly issued outside of countries with the US dollar as official currency, non-financial corporations only, unit: US dollar, monthly. Sources: Dealogic, ECB calculations.
New issuance of bonds outside denomination currency area, low or junk rating	Volume of debt capital denominated in euro (or the former currency of one of the 11 initial euro area countries) and newly issued outside of countries with the euro as official currency (pre-1999: outside of the initial member countries), low or junk rating only, monthly, unit: euro. Sources: Dealogic, ECB calculations.	Volume of debt capital denominated in US dollars and newly issued outside of countries with the US dollar as official currency, low or junk rating only, monthly, unit: US dollars. Sources: Dealogic, ECB calculations.
Portfolio investment – financial liabilities	Net incurrence of financial liabilities, euro area in fixed composition (19 countries) vis-à-vis rest of the world, not seasonally adjusted, monthly, at market value. Source: SDW (balance of payments and international investment position).	Net foreign purchases of US securities, not seasonally adjusted, monthly, at market value. Sources: TIC data, Haver Analytics.
Oil price (in US dollars, in euro)	Spot price of West Texas Intermediate. Source: FRED.	
Real exports to BRICS (excluding oil)	Sum of real exports from euro area to all BRICS countries, deflated by price indicators, excluding oil, monthly, sample: 2000-2018. Sources: Haver Analytics, ECB calculations.	Sum of real exports from the United States to all BRICS countries, deflated by price indicators, excluding oil, monthly, sample: 2000-2018. Sources: Haver Analytics, ECB calculations.
Real imports from BRICS (excluding oil)	Sum of real imports by the euro area from all BRICS countries; see real exports to BRICS (excluding oil).	Sum of real imports by the United States from all BRICS countries; see real exports to BRICS (excluding oil).

A3. Additional impulse responses

Figure A1: Response to a monetary policy tightening (bilateral model)

Interest rate differential

(one-month interbank lending rates, percentage points)

ECB tightening
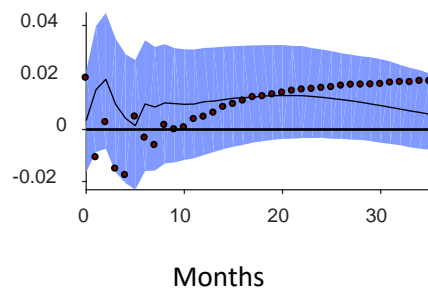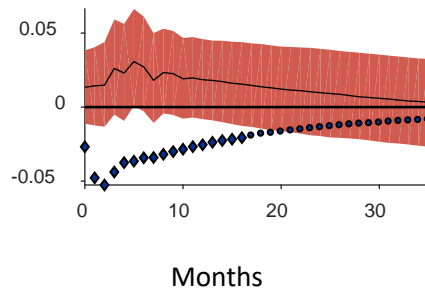

Federal Reserve tightening

Notes: The solid line shows the median impulse response surrounded by the 68% confidence band based on the bilateral model.

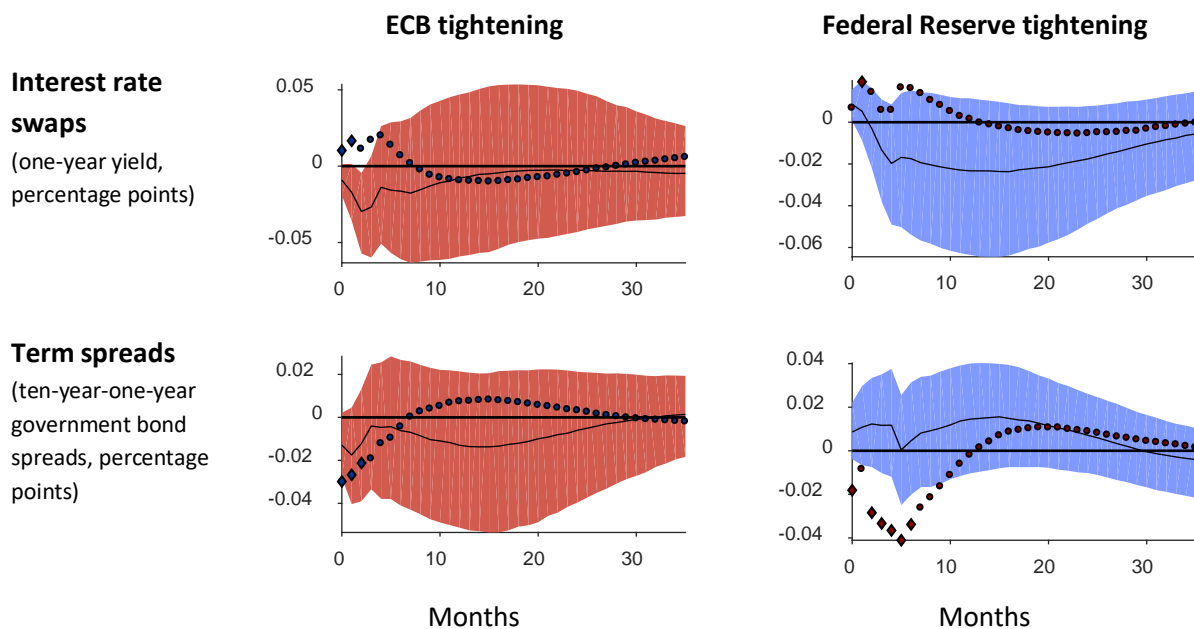## Figure A2: Spillovers from a monetary policy tightening to real activity and prices

ECB tightening

Federal Reserve tightening

Core HICP/ core CPI

(100 x log)

GDP deflator

(100 x log)

Real GDP

(100 x log)

Total real trade balance (excluding oil)
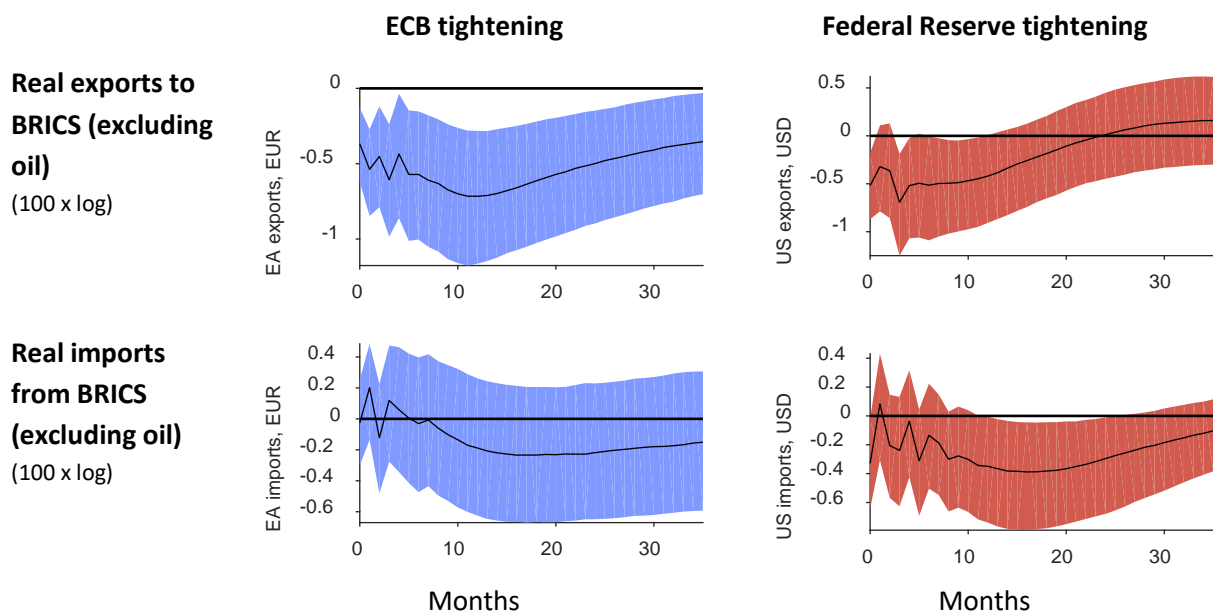(percentages of GDP)

Notes: The solid line plots the median spillover surrounded by the 68% confidence band. In the left-hand column these are the responses to an ECB tightening, in the right-hand column the responses to a Federal Reserve tightening. Quantities for the United States are plotted in red, quantities of the euro area in blue. The dotted lines plot the responses of the corresponding domestic variables, with diamonds symbolising significance at the 68% level. In the left-hand column these are the responses of euro area variables, in the right-hand column the responses of US variables.

Figure A3: Spillovers from a monetary policy tightening to financial conditions

ECB tightening · **Federal Reserve tightening**

Interest rate swaps
(one-year yield, percentage points)

Term spreads
(ten-year-one-year government bond spreads, percentage points)

Notes: The solid line plots the median spillover surrounded by the 68% confidence band. In the left-hand column these are the responses to an ECB tightening, in the right-hand column to a Federal Reserve tightening. Quantities for the United States are plotted in red, quantities of the euro area in blue. The dotted lines plot the responses of the corresponding domestic variables, with diamonds symbolising significance at the 68% level. In the left-hand column these are the responses of euro area variables, in the right-hand column the responses of US variables. The government bonds used are the Bund for the euro area and the Treasury for the United States.

Figure A4: Effects of a monetary policy tightening on global financial markets
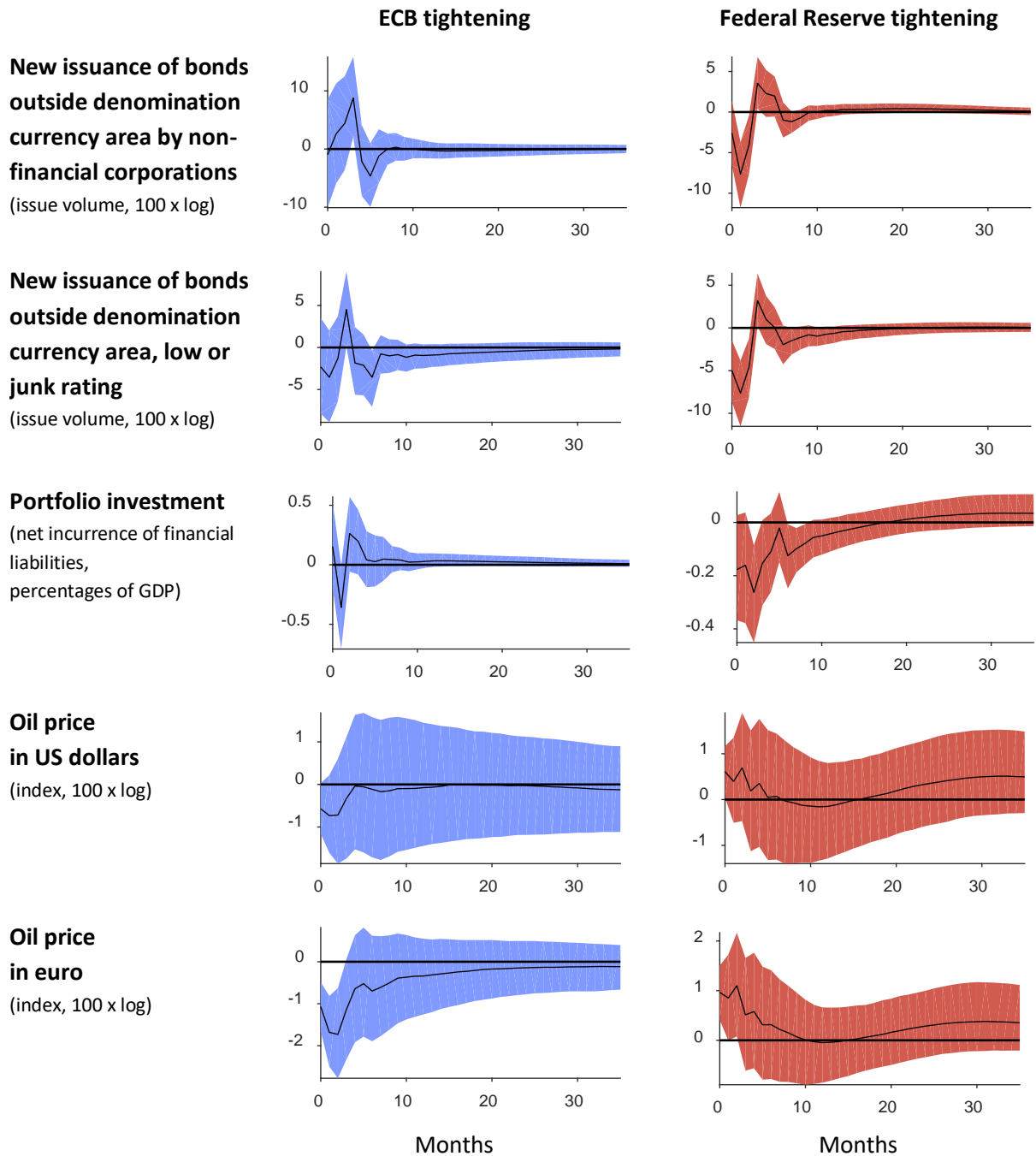
Notes: The solid line shows the median impulse response surrounded by the 68% confidence band. In the left-hand column these are the responses to an ECB tightening, in the right-hand column to a Federal Reserve tightening. Quantities related to the euro area are plotted in blue, quantities related to the United States in red.

Figure A5: Effects of a monetary policy tightening by the ECB or the Federal Reserve on emerging economies

ECB tightening

Federal Reserve tightening

Real exports to BRICS (excluding oil)
(100 x log)

Real imports from BRICS (excluding oil)
(100 x log)

Months

Months

Notes: The solid line shows the median impulse response surrounded by the 68% confidence band. In the left-hand column these are the responses to an ECB tightening, in the right-hand column the responses to a Federal Reserve tightening. (EA = euro area)

A4. Same-day press releases coordinated between the ECB and the Federal Reserve

Whereas both the ECB and the Federal Reserve operate under purely domestic mandates, they have taken joint policy action in the past on an ad hoc basis. This was always in response to an exceptional situation and in the face of large, *common* shocks. Table A3 shows the six most prominent instances of the ECB and the Federal Reserve announcing a policy change on the same day. The first two instances were in response to the terrorist attacks in the United States in 2001. The two Federal Reserve statements listed in the table maintain a rather domestic focus. The ECB press release on 17 September 2001, however, stresses that its decision is "in concert" with the Federal Reserve, continuing the line of "coordinating its activity with the Federal Reserve System" in its monetary policy statement five days earlier. The other four instances relate to the financial crisis starting in late 2007. Interestingly, both ECB and Federal Reserve statements highlight the coordination of their actions only at the peaks of the crisis, in March 2008 and October 2008, cumulating in a "joint statement by central banks" on 08 October 2008.

Table A3: Examples of same-day press releases explicitly coordinated between the ECB and the Federal Reserve

Date	Policy Action	Related Event	Reference to coordination	
			ECB	**Federal Reserve**
13 September 2001	Currency swap arrangement	Terrorist attacks of 11 September 2001	"the Federal Reserve and the European Central Bank have agreed on a swap arrangement"	Same as ECB
17 September 2001	Policy rate cut	Terrorist attacks of 11 September 2001	"in concert with this decision [of the Federal Open Market Committee]"	None
12 December 2007	Currency swap arrangement	Liquidity shortage	(list of central banks with same announcement) "joint action with the Federal Reserve"	(list of central banks with same announcement) no other reference to coordination
11 March 2008	Currency swap arrangement	Liquidity shortage (Bear Stearns rumours)	"central banks have continued to work together closely"	Same as ECB

08 October 2008	Policy rate cut	Lehman Brothers bankruptcy on 15 September 2008	"central banks ... have cooperated in unpre-cedented joint actions" "easing of global monetary conditions"	Same as ECB
31 October 2013	Standing bilateral currency swap arrangement	Liquidity shortage	(list of central banks with same announcement)	Same as ECB

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