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Central banks and macroeconomic policy choices: Relaxing the trilemma☆

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ABSTRACT

Macroeconomic policy choices in open economies are constrained by the trilemma according to which the objectives of exchange rate stability, monetary independence and capital mobility cannot be attained jointly. This paper shows that foreign exchange interventions provide an effective instrument to relax the trilemma. An active reserve policy allows central banks to pursue independent monetary and exchange rate policies when the capital account is liberalised.

We use the framework of the portfolio balance model to show that exchange market interventions may substitute for capital controls. Both allow a country to achieve the other two objectives of the trilemma. Our empirical analysis of a large country panel data set covering the period 1970–2010 confirms this theoretical insight: the weighted sum of the three trilemma objectives increases in the degree of foreign exchange market intervention. The capacity to relax the trilemma constraint has increased over time and has been most effective in emerging markets.

1. Introduction

The macroeconomic policy space in open economies is constrained by the trilemma, also known as impossible trinity. According to this tenet, the objectives of exchange rate stability, monetary independence and capital mobility are mutually inconsistent. Only two out of these three objectives can be attained jointly.

This paper shows in the theoretical framework of the portfolio balance model that foreign exchange interventions relax the trilemma constraint. Foreign exchange interventions are a substitute for capital controls: both allow a country to combine an independent monetary policy with a pegged exchange rate. This assertion is confirmed by our empirical analysis, which shows that the trilemma constraint is the looser, the stronger the degree of exchange market intervention.

While the trilemma suggests that central banks have binary choices, in practice, they can choose the degrees of exchange rate flexibility and of capital flow restrictions. Hence, in a world of intermediate regimes – managed exchange rates and imperfect capital controls – central banks face a trade-off: if they approach one trilemma variable, the weighted average of the other two variables decreases.

The trilemma can be derived from the Mundell–Fleming framework, in which the effectiveness of monetary policy depends on the exchange rate regime and the degree of capital mobility.[1] When the Nobel price was awarded to Robert Mundell, the Royal Swedish Academy of Science noted that the presence of the trilemma constraint "has become self-evident for academic economists" and its "insight is also shared by the majority of participants in the practical debate on stabilization policy" (Swedish Academy of Sciences, 1999, p. 8). In sharp contrast to its practical

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[1] The trilemma is indirectly present in models of currency crises. In the first generation of currency crisis models an inconsistency between monetary and exchange rate policy, which ignores the trilemma constraint, leads to a continuous loss of reserves and, consequently, to a currency crisis. If, in turn, international capital is not mobile, this inconsistency does not lead to a crisis.

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influence, approaches testing its empirical validity have been scarce until recently.

Empirical evidence in support of the trilemma is provided by Aizenman et al. (2010, 2011, 2013), Obstfeld et al. (2005) and Popper et al. (2013). The first authors show empirically that a move towards one goal of the trilemma induces a shift away from at least one of the other two policy objectives.

This paper contributes to this recent literature by examining the strictness of the trilemma constraint. It shows that the trilemma constrains economic policy only in the long run. All three objectives are jointly attainable in the short run if they are supported by accompanying policies. Changes in international reserves are such a policy to reconcile the trilemma.

If a central bank absorbs changes in the relative demand for domestic and foreign assets by proportional changes in reserves, it can neutralise the effects of an open capital account. This is possible if assets are imperfect substitutes or if capital mobility is restricted.

The contribution of this paper is twofold. It provides the theoretical framework and offers empirical evidence for our hypothesis that foreign exchange interventions relax the trilemma. First, we integrate central banks as additional actors in the portfolio balance model and show that foreign exchange intervention may substitute for capital controls. Foreign exchange intervention spans the same policy space as capital controls even if capital is perfectly mobile. Second, using data on the trilemma variables we provide empirical evidence that foreign exchange intervention relaxes the trilemma constraint and "achieves the impossible". More precisely, we show that the weighted sum of the trilemma variables increases in the degree of foreign exchange intervention. To this end, we provide new indexes of the degree of exchange market intervention.

Given a trend towards increasing capital mobility in industrialised, emerging and developing countries alike (see, for example, Aizenman et al., 2010), countries are left with the choice between a stable exchange rate and an independent monetary policy. "Fear of floating" (Calvo and Reinhart, 2002), in turn, induces emerging and developing countries to manage exchange rates.[2] As a consequence, monetary policy may become increasingly constrained.

As long as domestic policy choices go hand in hand with limited net capital flows, the trilemma may not be felt as restrictive. The constraint becomes evident in the face of large net capital flows, which besides domestic pull factors may result from abundant global liquidity and low interest rates in industrialised countries like in the recent financial crisis. This explains the renewed interest in the adequate policy response to capital inflows (see, among others, Bordo et al., 2015; Forbes and Warnock, 2012; Jinjarak et al., 2013; Korinek, 2010; Ostry et al., 2011).

The trilemma reflects a scarcity of instruments a la Tinbergen[3]: since a central bank has one policy instrument – the interest rate – it can only pursue one target – an exchange rate target or a monetary target – provided that capital is mobile. This paper argues that central banks are equipped with a second policy instrument: foreign exchange intervention.[4] Interventions enable a central bank to implement the same exchange rate and monetary targets as with capital controls.

The Reserve Bank of India (RBI) provides an example that central bank interventions do not only lean against the wind, but also against the trilemma. In the face of net capital inflows the trilemma is relaxed as long as reserves are accumulated. Since the late 1990s the RBI has engaged in sterilized foreign exchange market interventions to reduce the pressures on the Rupee: it continuously replaced domestic assets by foreign exchange reserves in its balance sheet (see Fig. 1). As a consequence, the stock of government bonds held with RBI had sharply fallen until 2004. This restricted the RBI's ability to engage in further sterilized purchases of reserves. To gain some leeway, the *Market Stabilisation Scheme* was launched in 2004. It allows the RBI to absorb liquidity from the domestic money market through the issue of government bonds. Government, in turn, is committed to deposit cash at the central bank equivalent to the amount of debt issued. This mechanism enables the central bank to sterilize the accumulation of international reserves even after its domestic assets have fallen to zero. This was indeed the case in 2007 when net domestic assets of the central bank turned negative. The intention of the mechanism is to broaden the central bank's ability to "maintain stability in the foreign exchange market and enable it to conduct monetary policy in accordance with its stated objectives" (Reserve Bank of India, 2004). In other words, it enables the central bank to relax the trilemma given that the Indian capital account is relatively open.

The remainder of the paper is structured as follows. The following section surveys the empirical literature on the trilemma focusing on its empirical validity and its relation to international reserve hoardings. Section 3 shows in the framework of the portfolio balance model that interventions in the foreign exchange market allow central banks to achieve all three goals of the trilemma jointly. Using the trilemma indexes, Section 4 examines empirically whether foreign exchange interventions soften the trilemma constraint. The final section concludes.

2. Literature review

2.1. Empirical tests of the trilemma constraint

Empirical tests of the trilemma constraint typically examine whether there is a negative relationship between exchange rate stability and the degree of monetary independence. The findings are inconclusive.

Shambaugh (2004) and Obstfeld et al. (2004, 2005) find strong evidence for the validity of the trilemma constraint: under pegged exchange rates interest rates follow more closely base country rates than in flexible exchange rate regimes. This holds for the eras of open capital markets, namely the gold era (1870–1914) and post Bretton Woods era. During the Bretton Woods period monetary policy is not found to be constrained, which might be explained by the presence of capital controls.

The findings of Rose (1996) are less favourable. While the relationship between monetary independence and exchange rate volatility is positive, it is neither statistically nor economically significant. Frankel et al. (2004) show that in the long run domestic interest rates are determined by international ones independently of the exchange rate regime. According to Bluedorn and Bowdler (2010) the nature of the interest rate change is crucial for its transmission: exogenous interest rate shocks show a greater concordance with the trilemma prediction than anticipated changes. Obstfeld (2014) emphasises that short-term interest rates are more independent than long-term rates and that despite financial globalisation monetary independence increases if exchange rates are pegged.

While the results of Klein and Shambaugh (2013) support the trilemma constraint, the authors focus on intermediate policies, namely managed exchange rates and partial capital controls. Their empirical results show that these "rounded corners" of the

[2] This reduces the trilemma to a dilemma as noted by Shambaugh (2004).

[3] The Tinbergen rule states that for each policy target there must be at least one policy instrument.

[4] In a similar vein, Ostry et al. (2012) emphasise that sterilized foreign exchange market intervention constitutes a second instrument, which enables a central bank to limit currency movements in the context of an inflation targeting framework.

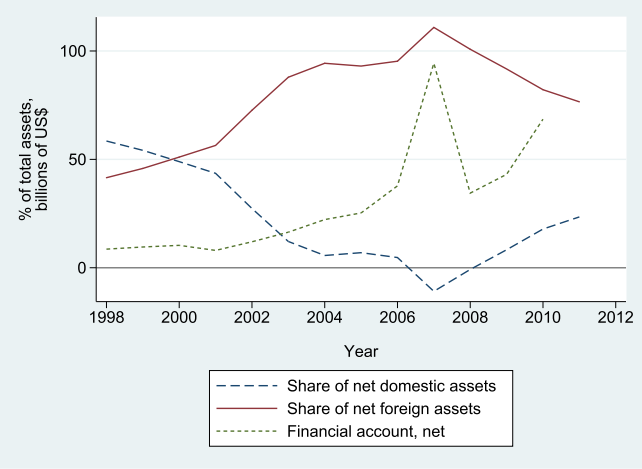

Fig. 1. Sterilization of capital inflows in India. *Notes.* The sterilization of capital inflows by the Reserve Bank of India is reflected by changes in the composition of its assets. Net domestic and net foreign central bank assets are expressed as shares of total assets. Net domestic assets are calculated as the sum of claims on government, claims on banks and the commercial sector and government currency liabilities to the public. Net foreign assets consist of gold holdings and foreign exchange reserves. The financial account balance is included to account for net private capital flows to India. *Data source:* Reserve Bank of India (2012) and IFS (2012).

trilemma provide more monetary autonomy than "hard corners" (fixed exchange rate, closed capital account).

Aizenman et al. (2009) provide a direct test whether the trilemma trade-off is valid. Their trilemma index measures the degree to which the objectives of the trilemma have been achieved. In particular, each objective is represented by an index: a monetary independence index, an index of exchange rate stability and a capital mobility index. They regress a constant on these variables controlling for the three trilemma dimensions. The goodness of fit is high, which is interpreted as evidence that the trade-off between the trilemma objectives is subsistent.

2.2. Causes and implications of trilemma choices

A dynamic analysis of the individual indexes over time reveals that policy choices have been changing over time. There are two major reasons for moves within the trilemma space: changes in the international monetary system and shifts in preferences.

First, the architecture of the international monetary system imposes an additional constraint on countries' choices within the trilemma. The architecture might force a central bank to pursue policies in favour of one trilemma objective, thereby reducing its policy space to a two-dimensional problem. Examples are the gold standard characterised by stable exchange rates and mobile capital and the Bretton Woods system, which imposed fixed exchange rates and monetary independence at the expense of capital mobility.

Second, the trilemma configuration might be changing because of changing preferences. For the post Bretton Woods period Aizenman et al. (2009, 2013) show that since the beginning of the 1990s industrialised countries have been moving to higher capital mobility at the expense of monetary independence. In emerging markets exchange rate stability decreased during the 1970s and capital mobility has been increasing since 1990. Both developments are also observable in developing countries, albeit at a slower pace. In general, emerging markets seem to move to the middle ground characterised by moderate levels of the trilemma objectives.

Aizenman et al. (2010, 2011) examine the economic effects of policy choices within the trilemma space. They find that greater monetary independence is associated with lower output volatility and higher inflation compared to a trilemma configuration prioritising a fixed exchange rate.

2.3. Trilemma and the level of reserves

Obstfeld et al. (2010) explain the accumulation of reserves since the 1990s as a policy that counteracts the effects of volatile capital flows coupled with increasing financial integration. Reserve accumulation is considered as a by-product of a shift in the trilemma configuration towards capital mobility.

In this vein, Aizenman et al. (2013) suggest that the accumulation of reserves is related to the move of the trilemma configuration in emerging and developing countries towards the middle ground. In other words, reserves are considered as a buffer that enhances the stability of the trilemma variables. Popper et al. (2013) focus on the stability of the trilemma configuration over time. They find that a change in the configuration is less likely if the trilemma is supported by large reserve holdings.

Aizenman et al. (2010) argue that sizeable holdings of international reserves might be conducive to increase one trilemma variable while the other two objectives are held constant. Comparing low-reserve with high-reserve countries Aizenman et al. (2010) find that the latter group's weighted average of the three trilemma variables is significantly larger than in the low-reserve countries.[5] Higher reserves relax the trilemma.[6] While these papers focus on the stock of reserves, we argue that the flow of reserves my soften the trilemma constraint.

In a cross-section analysis for the global financial crisis of 2008–2010, Bussière et al. (2015) show that both the pre-crisis level of reserves and the existence of capital controls are positively related to economic growth. This is, both are used to buffer external shocks.[7]

2.4. Exchange rate and reserve accumulation

The literature on exchange market intervention focuses on one trilemma variable: it examines whether changes in reserves affect the exchange rate. In general, the literature is inconclusive with respect to the effectiveness of foreign exchange market interventions.[8] Until the 1980s, conventional wisdom was that sterilized intervention is effective at most in the short run. Beginning in the 1990s, studies found significant effects of interventions in industrialised countries (see, among others, Dominguez and Frankel, 1993). Only recently, this was also confirmed for emerging markets (Daude et al., 2014; Menkhoff, 2013). Findings with respect to the effects of interventions on the volatility of exchange rates are mixed. If there is an effect at all, volatility is reduced in the long run (see Melvin et al., 2009). A stable exchange rate, in turn, favours trade and is conducive for growth and employment (see, among others, Aghion et al., 2009; Bacchetta and van Wincoop, 2000; Menkhoff, 2013).

[5] Aizenman et al. (2010) divide their sample into low-reserve and high-reserve countries using a threshold level of reserves relative to GDP of 21%.

[6] Aizenman (2013, p.13) notes: "The experience of EMs [emerging markets] suggests that the Trilemma triangle, while useful, overlooks the possibility that with limited but growing financial integration, countries hoarding international reserves may loosen in the short-run some of the Trilemma constraints."

[7] Bussière et al. (2015) consider reserves and capital controls rather as complements than substitutes because the marginal effect of reserves on economic growth is larger in the presence of controls. This effect, however, disappears after outliers have been dropped from the sample.

[8] For surveys see Edison (1993) and Sarno and Taylor (2001). Fatum and Hutchison (2003) provide an event study of sterilized intervention.

While a policy of leaning against the wind is consistent with a stable level of reserves in the long run – sales and purchases of reserves balance each other – asymmetric or persistent exchange market interventions affect the level of reserves. The literature shows that central banks may accumulate reserves to stabilize or undervalue the exchange rate.

Levy-Yeyati et al. (2013) document a "fear of appreciation" in the sense that central banks intervene in the foreign exchange market to depreciate the exchange rate or to postpone its appreciation. In a similar vein, Adler and Tovar (2011) show that sterilized exchange market interventions were effective to slow the pace of appreciation in the 2000s. For a sample of six Asian economies, Pontines and Rajan (2011) find that interventions are asymmetric: central bank interventions are stronger in the face of appreciations than depreciations.

One strand of the literature on international reserves argues that their accumulation is driven by mercantilist motives (Aizenman and Lee, 2007; Dooley et al., 2003). Central banks accumulate reserves to maintain an undervalued exchange rate. Korinek and Serven (2010) show that this may be welfare improving if the tradeable sector is characterised by learning-by-investing externalities.

Löffler et al. (2012) examine the case of capital inflows and appreciating pressures on the exchange rate. They argue that monetary policy is limited independently of the chosen exchange rate regime: while sterilized reserve accumulation may allow central banks to gain monetary policy independence in the case of fixed exchange rates, this policy causes costly distortions in the domestic financial system. In the case of flexible exchange rates, central bank policy may be affected by reserve accumulation in the past: monetary policy independence is limited when it entails substantial revaluation losses and sterilization costs.

3. Model of a relaxed trilemma

This section presents a simple portfolio balance model to illustrate that changes in international reserves may relax the trilemma constraint. The model shows that capital controls and changes in reserves may be regarded as substitutes. Both allow a central bank to manage net capital inflows and to balance changes in the relative demand for assets. As a consequence, alike capital controls, exchange market interventions make an independent monetary policy compatible with a stable exchange rate.

The portfolio balance model is a dynamic approach to exchange rate determination. It assumes that the equilibrium exchange rate is the outcome of the interaction of international asset markets and current account balances. The model relaxes the interest rate parity condition and assumes imperfect substitutability between assets instead.[9,10]

Our exposition follows the portfolio balance model as developed by Blanchard et al. (2005), who incorporate valuation effects in their analysis.[11] In equilibrium, the current account is balanced and the net foreign asset position is constant. The debtor country finances interest payments on its net debt position by a trade surplus.

Our contribution to the model is to explicitly introduce the central bank as an additional actor. While the standard model assumes that exchange rates are determined by market forces, we allow central banks to affect the exchange rate behaviour via foreign exchange market intervention.[12] We show that central bank intervention allows to accomplish all three policy goals of the trilemma jointly.

Our model considers two countries, the US and a foreign country, which represents the rest of the world. There are two assets, US and foreign bonds. The wealth of US investors (W), measured in units of US goods, can be expressed as the difference between the stock of US assets (X) and the US net debt position with regard to the foreign country (F):

$$W = X - F \tag{1}$$

The same relationship holds for the foreign country, whose variables are denoted by an asterisk: foreign wealth (W^*) and the stock of foreign assets (X^*) are expressed in terms of foreign goods. Since the US and the foreign country form a closed economy, the net debt position of the US (F) equals the net foreign asset position of the foreign country:

$$\frac{W^*}{E} = \frac{X^*}{E} + F \tag{2}$$

where the real exchange rate (E) is defined as the price of US goods in terms of foreign goods (a decrease in E corresponds to a depreciation of the dollar).

The gross real rate of return on assets depends on their rate of interest and exchange rate changes. Due to the assumption of imperfect asset substitutability, uncovered interest parity need not be satisfied.[13] The expected gross real rate of return of US relative to foreign assets can be expressed as:

$$R^e = \frac{1+r}{1+r^*}\frac{E^e_{+1}}{E} \tag{3}$$

where r and r^* denote US and foreign real interest rates, respectively. E^e_{+1} is the expected real exchange rate one period ahead.

To this setting with two types of private investors – US and foreign ones – as in Blanchard et al. (2005), we add a third investor: the foreign central bank.[14,15] Its balance sheet, expressed in terms of foreign goods, is given by:

$$M^* + R^* = X^{CB^*} = B^* + IR \cdot E \tag{4}$$

where M^* denotes foreign currency in circulation and R^* are deposits of private banks held at the central bank. The assets of the foreign central bank X^{CB^*} consist of foreign assets B^* and international reserves (IR), which are held in form of US assets. The total amount of foreign assets is supplied by private investors (X^{PR^*}) and the foreign central bank:

$$X^* = X^{PR^*} + X^{CB^*} \tag{5}$$

[9] For the foundations of the portfolio balance model refer to Branson (1977), Henderson and Rogoff (1982) and Kouri (1983) among others.

[10] The basic idea that the exchange rate adjusts to balance demand and supply for foreign exchange is already present in Goschen (1861, p.44): "In the first case, those who have bills to draw [] will not find sufficient purchasers to take all their bills; for only those will buy who have debts abroad to settle, and these debts are by our hypothesis of less amount than the claims. Accordingly the exporters, competing with each other for the sale of the bills, will take less money for them than their nominal par value; that is to say, will sell them at a discount."

[11] In comparison to the standard model Blanchard et al. do not consider the money market explicitly.

[12] In our model, central bank intervention affects the exchange rate via its effect on the supply and demand for assets (portfolio-balance channel). Alternatively, intervention might be effective through the signalling channel and the coordination channel (see Beine et al., 2009). On the relationship between size and effect, refer to Fatum and Yamamoto (2014).

[13] The empirical rejection of the uncovered interest rate parity, especially for non-industrialised countries, may be regarded as support of the portfolio balance model.

[14] In the model, the foreign central bank represents the entire foreign government sector. While foreign exchange market intervention is usually a central bank instrument, in some countries - e.g. Japan - the Ministry of Finance or other official entities have the sole authority for intervention.

[15] We abstain from explicitly modelling the US central bank. We assume that it is passive and, foremost, does not intervene in the foreign exchange market.

Investors can choose between US and foreign assets. US investors allocate a share α of their wealth to US assets and a share $(1-\alpha)$ to foreign assets. In the foreign country, private investors and the central bank determine the composition of their portfolios independently of each other. Foreign private investors dedicate a share α^{PR^*} of their wealth to foreign assets and invest a share $(1-\alpha^{PR^*})$ in US assets. These shares of private investors increase in the expected relative gross return of the respective asset:

$$\alpha = \alpha(R^e), \quad \alpha^{PR^*} = \alpha^{PR^*}(R^e) \quad \text{with} \quad \alpha_{R^e} > 0, \quad \alpha^{PR^*}_{R^e} < 0 \quad \text{and} \quad 0 \le \alpha, \alpha^{PR^*} \le 1 \tag{6}$$

The asset composition of the foreign central bank, in turn, is independent of the relative return. Let $(1-\alpha^{CB^*})$ denote the fraction of total foreign central bank wealth X^{CB^*} devoted to international reserves. This share is used as a policy instrument; its choice aims at allowing an independent monetary policy under a fixed exchange rate and perfect capital mobility. The change in international reserves (IR) at the central bank can be expressed as:

$$dIR = -d\alpha^{CB^*} \cdot \frac{X^{CB^*}}{E} \tag{7}$$

The market for US assets is in equilibrium if the supply of US assets (X) equals the demand for US assets by US and foreign private investors and by the foreign central bank:

$$X = \alpha(R^e)W + (1-\alpha^*)\frac{W^*}{E} \tag{8}$$

where α^* is a weighted average of α^{PR^*} and α^{CB^*}. Using Eqs. (1), (2) and (5), this condition can alternatively be expressed as:[16]

$$X = \alpha(R^e)(X-F) + (1-\alpha^{PR^*})\left(\frac{X^{PR^*}}{E} + F\right) + (1-\alpha^{CB^*})\frac{X^{CB^*}}{E} \tag{9}$$

We now turn to the evolution of the net foreign asset position of the foreign country, which is given by[17]

$$dF = rF + (1+r)(1-\alpha)\left(1 - \frac{1+r^*}{1+r}\frac{E}{E_{+1}}\right)(X-F) + D(E) \tag{10}$$

where $D(E)$ is the US trade deficit.[18] $D(E)$ is assumed to increase in E. The three terms on the right-hand side account for the following effects: the foreign country accumulates assets thanks to (1) interest income in the presence of an existing positive net foreign asset position, (2) excess returns on its gross holdings of foreign assets and (3) a trade surplus.[19] By definition, the change in the net foreign asset position equals the current account balance.[20]

In this framework, we examine the following policy: the foreign central bank implements an independent monetary policy by choosing its preferred interest rate in the first place. The US interest rate is assumed to be exogenous and constant. Furthermore, the foreign central bank credibly fixes the real exchange rate such that $E = E^e_{+1}$. As a consequence, the relative return R^e is given and, by implication, asset shares α and α^{PR^*} are predetermined. Eq. (9) can be solved for the equilibrium real exchange rate:

$$E = \frac{(1-\alpha^{PR^*})X^{PR^*} + (1-\alpha^{CB^*})X^{CB^*}}{(1-\alpha)X + (\alpha + \alpha^{PR^*} - 1)F} \tag{11}$$

We proceed by considering three different scenarios.

Case 1: perfect capital mobility

In this section, we assume that assets are imperfect substitutes but capital is perfectly mobile. We define perfect capital mobility as a situation where international capital flows are not affected by de jure restrictions. Under perfect capital mobility with independent monetary policy, the policy trilemma arises: the exchange rate is endogenous and given by Eq. (11). Exchange rate adjustments guarantee that asset markets are cleared. The exchange rate reaches its long-run equilibrium when F is constant, that is, when the sum of interest payments on F and excess returns equal the trade balance D.

Case 2: capital controls

Capital account openness may be limited by legal restrictions. These include quantitative limits, prohibitions and taxes on capital inflows and outflows. In the presence of quantitative restrictions, the share of wealth, which investors are allowed to allocate to assets of the other country, may deviate from the share that would be individually optimal. In the foreign country, controls on capital inflows determine α whereas controls on outflows affect α^{PR^*}. The effective shares α and α^{PR^*} are used as policy instruments. They guarantee that asset markets are cleared at the given exchange rate. Consequently, the central bank can pursue an autonomous monetary policy and peg the exchange rate (see Eq. (11)).

A tax on capital flows drives a wedge between market interest rates and effective return.[21] This form of capital controls affects the optimal shares α and α^{PR^*}, which are chosen by private investors. Hence, the central bank steers α and α^{PR^*} indirectly by affecting the choices of private investors. Furthermore, in the case of an unremunerated reserve requirement part of the capital inflow ends up at the central bank. During the holding period, the effective share α^{eff} can be expressed as $\alpha^{eff} = \alpha(1-\theta)$, where θ represents the fraction of the investment to be deposited at the central bank.[22]

A further policy instrument to affect private agents' asset shares are minimum reserve requirements imposed on private banks. Minimum reserve requirements affect relative returns. If the foreign central bank raises the minimum reserve ratio, this may affect the share of domestic to foreign assets such that the need for central bank intervention is reduced.

These different types of controls share the characteristic that they allow a central bank to steer α and/or α^{PR^*} such that the exchange rate peg is sustainable.

Case 3: perfect capital mobility with central bank intervention

Assume that the economy is characterised by a pegged exchange rate and perfect capital mobility. The central bank sets its preferred interest rate in the first place. It then engages in a foreign exchange market intervention to keep E constant. X^{CB^*} is given. The foreign central bank does not extend its balance sheet by an expansionary monetary policy or a change in its minimum reserve requirements.[23] It may, however, engage in an accounting

[16] We assume that profits or deficits of the foreign central bank are carried over to the public. This allows us to hold X^{CB^*} constant over time. This simplification does not affect our major findings.

[17] For details refer to Blanchard et al. (2005).

[18] By implication $D(E)$ represents the trade surplus of the foreign country.

[19] The change in foreign assets can, alternatively, be expressed in terms of foreign variables. $dF = r^*F + (1+r)(1 - \frac{1+r^*}{1+r}\frac{E}{E_{+1}})[(1-\alpha^{PR^*})(\frac{X^{PR^*}}{E} + F) + (1-\alpha^{CB^*})\frac{X^{CB^*}}{E}] + D(E)$.

[20] Under our assumption of successful stabilization of the exchange rate and exchange rate expectations, valuation effects as those discussed in Blanchard et al. (2005) are absent.

[21] By way of example, the unremunerated reserve requirement requires investors to deposit a given fraction of the capital inflow without interest payment at the central bank. The holding period is fixed.

[22] This policy extends the central bank's balance sheet without affecting money supply.

[23] Remember that this does not mean that there is no room for monetary policy. The preferred interest rate has been set in the first step.

exchange on the asset side: it can exchange foreign assets B^* for international reserves IR and vice versa. This is, it sets α^{CB^*}. In other words, foreign exchange market interventions are assumed to be sterilized. Differentiating Eq. (11) gives:

$$dE = -\frac{(\alpha + \alpha^{PR^*} - 1)E \cdot dF + X^{CB^*} \cdot d\alpha^{CB^*}}{(1-\alpha^{PR^*})\frac{X^{PR^*}}{E} + (1-\alpha^{CB^*})\frac{X^{CB^*}}{E}} \tag{12}$$

To keep E at the given level ($dE = 0$), the central bank buys or sells dollar assets in exchange for foreign assets. The necessary change in the share of foreign assets in its balance sheet can be expressed as

$$d\alpha^{CB^*} = -\frac{(\alpha + \alpha^{PR^*} - 1)dF}{\frac{X^{CB^*}}{E}} \tag{13}$$

By implication, the necessary change in international reserves to keep E fixed is given by

$$dIR = (\alpha + \alpha^{PR^*} - 1)[rF + (1-\alpha)(r - r^*)(X - F) + D(E)] \tag{14}$$

where Eq. (13) is inserted in Eq. (7). The change in reserves depends positively on the current account balance: the accumulation of foreign reserves is a positive function of (i) the income stream stemming from the net foreign asset position of the foreign country, (ii) excess returns on its US assets and (iii) the surplus in its trade balance. The necessary reserve change is the larger, the stronger the home bias in both countries is (large α,α^{PR^*}). Fig. 2 visualises the reserve accumulation resulting from exchange rate stabilization as a function of the net foreign asset position for given dF.

Assume that the economy starts in period 0 with a balanced net foreign asset position ($F_0 = 0$). The exchange rate is pegged at $\bar{E}$, which is larger (that is, undervalued from the perspective of the foreign country) than the equilibrium exchange rate E_0. The foreign trade balance is in surplus at the pegged exchange rate ($D(\bar{E}) > 0$). The foreign economy accumulates net foreign assets, which generate a positive income stream in future periods. As a consequence, wealth of the US decreases, while foreign wealth increases. For given shares α and α^{PR^*}, US demand for US assets decreases and foreign demand for US assets increases. For $\alpha = \alpha^{PR^*} = 0.5$ these changes counterbalance and the market for US assets is in equilibrium at the given exchange rate. In general, Eq. (14) shows that for $\alpha + \alpha^{PR^*} = 1$ the equilibrium exchange rate is independent of wealth transfers (dF) and constant over time.

If the economies are characterised by home bias,[24] however, the fall in US demand is only partly offset by an increase in foreign demand for US assets. To keep E unchanged, the foreign central bank has to offset the lower private demand for US assets: it purchases US assets (= international reserves) and sells foreign assets equal to $\beta \cdot C$ where $\beta = \alpha + \alpha^{PR^*} - 1$ and $C = (1-\alpha) \cdot (r - r^*)X + D(\bar{E})$. The foreign central bank acts as a "demander of last resort". The sale of foreign assets satisfies the increasing demand for foreign assets by foreign investors due to their increasing wealth.[25]

Although the surplus of the trade balance $D(\bar{E})$ is constant, the foreign current account balance increases over time because of returns of the increasing net foreign asset position. As a consequence, the pegged exchange rate $\bar{E}$ requires the foreign central bank to accelerate its reserve accumulation over time. More precisely, the necessary change in reserves in period t is given by

$$dIR_t = \beta C \cdot (1+\gamma)^t \tag{15}$$

where $\gamma = r^* + \alpha(r - r^*)$. Since $\gamma > 0$ per definition, this expression diverges. The right-hand panel of Fig. 2 visualises this relationship. It shows that the magnitude of foreign exchange market intervention rises over time because the equilibrium exchange rate diverges from its pegged value.

Theoretically this type of central bank intervention is limited by an upper bound: when the central bank holds all its assets in the form of international reserves ($\alpha^{CB^*} = 0$), it can no longer sterilize the accumulation of reserves. In practice, however, if the central bank is allowed to be a net debtor with respect to the domestic economy, it can issue domestic assets to finance the purchase of reserves and there exists no clear limit to sterilized reserve accumulation.[26]

In other words: if assets are imperfect substitutes, central banks can pursue an independent monetary policy and peg the exchange rate even in the face of perfect capital mobility. They can reach all three goals of the policy trilemma jointly. The instrument is sterilized exchange market intervention that changes the level of international reserves.

In this version of the model with predetermined asset shares and constant global wealth, private capital flows are the result of a wealth transfer between both countries. In addition, capital flows arise when there are differences in economic growth between the two regions. Assume that real output grows at a rate g in the US, but is constant in the foreign country. As a consequence, US assets also grow at a rate g such that X of the following period may be computed as $X_{g,+1} = X(1+g)$. Since US private investors allocate a share $(1-\alpha)$ of their wealth to foreign assets, this induces a net capital flow from the US to the foreign country amounting to $(1-\alpha)gX$. With the supply of foreign assets being constant, asset market equilibrium requires the real exchange rate to appreciate (from the perspective of the foreign country). Eq. (13) then reads as

$$d\alpha^{CB^*} = -\frac{(\alpha + \alpha^{PR^*} - 1)dF + (1-\alpha)XdG}{\frac{X^{CB^*}}{E}} \tag{16}$$

In the face of net capital flows to the foreign country, the foreign central bank has to increase $(1-\alpha^{CB^*})$ and accumulate reserves to keep E constant even if the exchange rate is at its equilibrium level at the beginning of the period ($E_0 = \bar{E}$).

The analysis so far assumed that investors trust in the central bank's announcement of a fixed exchange rate, that is $E^e_{+1} = E$. If there are expectations of an exchange rate adjustment, the defence of the exchange rate peg requires the central bank to intervene more heavily on the foreign exchange market compared to the case with adaptive expectations. By way of example, if agents expect a depreciation of the foreign currency ($E^e_{+1} > E$), expected returns of US relative to foreign assets increase and assets are reallocated towards US assets. This asset reallocation depreciates the foreign currency. To defend the exchange rate the central bank has to offset these changes in US relative to foreign assets by an appropriate shift in its asset composition. This is, if announced domestic monetary policy causes expectations of an adjustment in the exchange rate, central bank intervention has to be stronger to defend the trilemma objectives.

In addition to exchange rate expectations, expected relative returns are affected by the riskiness of the investment. Risk, in turn, is related to institutional quality, default probabilities, enforceability of creditor rights and the likelihood of financial and economic crises. All these variables might change and be affected by shocks. Finally, changes in US interest rates, which are exogenous from the

[24] Home bias is defined as $\alpha(R^e) + \alpha^{PR^*}(R^e) > 1$.

[25] For the theoretical case of portfolios biased towards foreign assets ($\alpha(R^e) + \alpha^{PR^*}(R^e) < 1$) $\beta < 0$ and the foreign central bank has to defend an undervalued exchange rate by a sale of reserves.

[26] This policy has been pursued by the Reserve Bank of India, whose share of net domestic assets became negative in 2007 resulting in net liabilities towards central government. All assets were held in the form of international reserves (refer to Fig. 1). Löffler et al. (2012) refer to central banks that aim at absorbing liquidity from the domestic financial system using policy operations on the liabilities side – e.g. the issuance of government bonds or government deposits – as 'debtor central banks'.

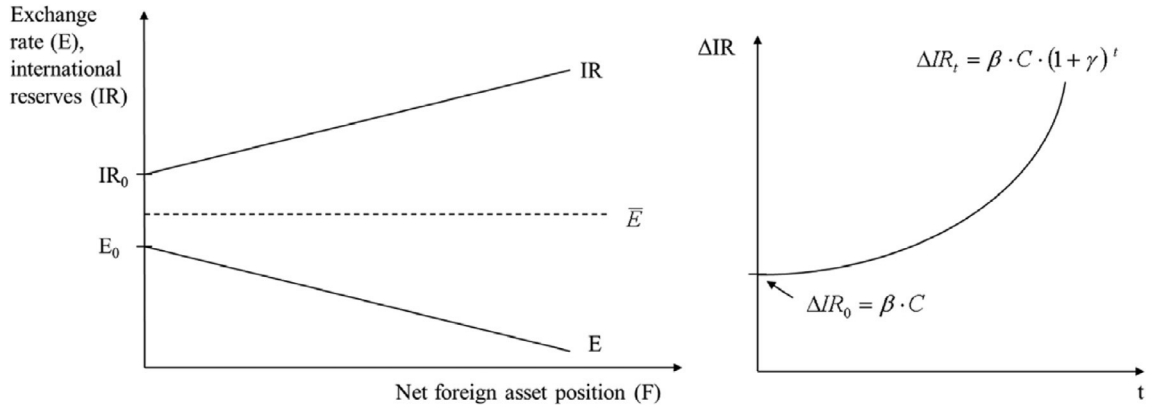

Fig. 2. Portfolio balance model: reserve accumulation under fixed exchange rate. *Notes.* The left-hand graph illustrates the evolution of the net foreign asset position and international reserves of a country that defends its exchange rate in the face of appreciation pressures: the exchange rate is pegged at $\bar{E}$, while the initial equilibrium exchange rate without central bank intervention is given by E_0. The difference between $\bar{E}$ and E corresponds to the necessary exchange rate adjustment when the central bank stops intervening. The right-hand graph shows how reserve accumulation evolves over time as a consequence of exchange rate targeting.

perspective of the foreign economy, might induce capital flows. These factors have in common that they affect α and α^{PR*}. Eq. (11) shows that changes in α and α^{PR*} may be offset by an adjustment in α^{CB*} such that E remains constant.

This section has shown that for a given monetary policy a central bank disposes of two policy instruments to maintain an exchange rate target: capital controls and foreign exchange market intervention. Both are substitutes. The three trilemma objectives are jointly compatible if the exchange rate is managed via interventions. This result is visualised in the trilemma triangle of Fig. 3.

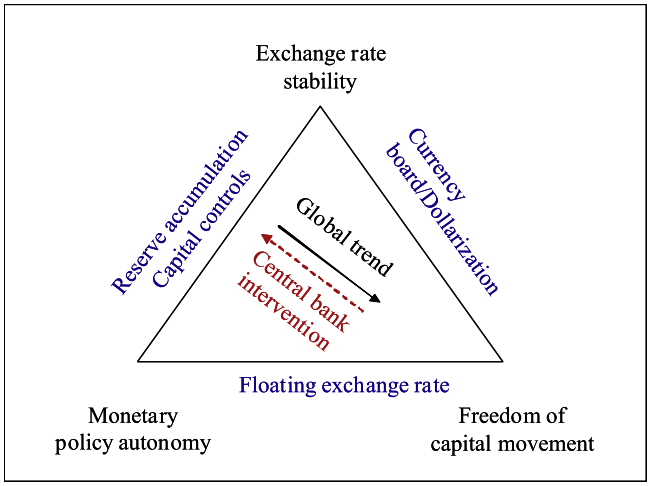

Fig. 3. Macroeconomic trilemma: capital controls and reserve accumulation as substitutes. *Notes.* This figure illustrates that capital controls and reserve accumulation are substitutes in the macroeconomic trilemma: both allow a country to pursue an independent monetary policy and to maintain a stable exchange rate.

4. Empirical evidence of a relaxed trilemma

This section takes the theoretical result to the data. It test whether changes in reserves relax the trilemma. The empirical study is carried out on the basis of a pooled data set of cross-country and time-series observations. It contains annual data from 1970 to 2010 for a large number of industrialised, emerging and developing countries, which are listed in Appendix A. Variable definitions and data sources can be found in Appendix B.

4.1. Methodology

The empirical analysis is based on the trilemma indexes developed by Aizenman et al. (2009). Each objective is represented by an index: the monetary independence index is calculated as the correlation of the country's interest rate with the interest rate of a base country where the base is chosen in line with Shambaugh (2004). Higher correlations indicate less monetary independence. The index for exchange rate stability is based on the inverse of the annual standard deviation of monthly exchange rates between home and base country. Small standard deviations signal relatively stable exchange rate regimes. Capital mobility is captured by the Chinn–Ito index, which is derived from IMF data on de jure exchange restrictions.[27] All three indexes are normalised between 0 and 1. Higher index values indicate that policy is closer to the respective objective.

To explore the trilemma constraint, we follow the approach pioneered by Aizenman et al. (2009, 2013) and regress the constant one on the three trilemma variables. We then augment this "trilemma equation" by an additional factor, namely a measure for exchange market intervention. The resulting "quadrilemma equation" reads as

$$1 = \alpha ERS_{it} + \beta MI_{it} + \gamma KAOPEN_{it} + \delta INT_{it} + e_{it} \quad (17)$$

where *ERS* controls for the stability of the exchange rate, *MI* is the measure of the independence of monetary policy, *KAOPEN* accounts for the de jure openness of the capital account and *INT* is our measure of the intensity of exchange market intervention. *i* denotes a specific country and *t* represents the time period. This specification implicitly assumes a linear relationship between the quadrilemma variables. If the coefficients of the first three trilemma variables are positive, this supports the idea of a trade-off among the three objectives: if a country moves closer to one objective, it consequently veers away from at least one of the remaining two objectives. With respect to the intervention variable, theory suggests a negative coefficient: intervention allows countries to increase the weighted sum of the three trilemma variables. That is, they might move towards one objective without giving up the other two. A good fit is considered as evidence in favour of the trilemma constraint.

[27] More precisely, Chinn and Ito (2006) calculate the index of capital account openness as the first principal component of the following binary indicators: restrictions on current and capital account transactions, multiple exchange rates and the required surrender of export proceeds.

4.2. Measures of exchange market intervention

We use two different empirical measures of exchange market intervention: (1) the change in central banks' international reserves relative to the change in private external indebtedness and (2) the share of exchange market pressures buffered by reserve changes. We calculate our measures of intervention using data for reserve changes from the balance of payments statistics. These provide data on reserve flows net of valuation changes, which might result from price changes or exchange rate fluctuations.[28] Additional information concerning the calculation and interpretation of these two measures may be found in Appendix C.

4.2.1. Reserve changes relative to private capital flows

In line with Eq. (14), a constant exchange rate requires international reserves to be a positive function of the private accumulation of external assets. An increasing net foreign asset position raises domestic wealth. Given a home bias, agents are not willing to invest their increasing wealth in foreign assets at the given exchange rate. Therefore, the central bank has to absorb foreign assets and provide domestic assets to domestic agents by sterilised foreign exchange market interventions. In other words, it balances the disequilibrium on the market for domestic and foreign assets such that the exchange rate does not have to adjust. The larger the increase in net foreign assets, the higher the necessary increase in reserves. In general, the accumulation of reserves in the face of increasing private net foreign assets reduces the exchange rate adjustment.[29] We therefore hypothesise that the relaxation of the trilemma is a positive function of the degree to which reserve changes offset changes in private external debt. Accordingly, we compute the ratio of flows in reserve assets derived from the balance of payments ΔIR over the change in private net foreign assets ΔNFA^{PR} as our measure of exchange market intervention:

$$INT^F_{it} = \frac{\Delta IR_{it}}{\Delta NFA^{PR}_{it}} \tag{18}$$

The superscript F indicates that this intervention index is based on capital **f**lows.

4.2.2. Reserve changes relative to exchange market pressure

The preceding method assumes that pressures on the exchange rate depend on the cross-border transfer of wealth measured by the change in countries' net foreign asset positions. As an alternative approach, we calculate the pressures on the exchange rate directly making use of the exchange market pressure index (EMPI) provided by Eichengreen et al. (1996).

We define the index of intervention activity as the proportion of exchange market pressures buffered by changes in reserves:

$$INT^P_{it} = -\frac{1}{\sigma^{IR}_i}\frac{\Delta IR_{it}}{IR_{it}}\frac{1}{EMPI_{it}} \tag{19}$$

where the standard deviation σ is calculated individually for each country over the whole period. The superscript P indicates that this intervention index measures reserve changes relative to exchange market pressures. An index following the same basic ideas was introduced by Weymark (1995).

The upper panel of Fig. 4 illustrates the evolution of cross-section averages across time of these two measures of exchange market intervention. Both measures fluctuate around zero implying that there are periods when central banks lean against the wind and periods when their interventions strengthen market forces. The lower panel shows that in most periods reserve changes where positive on average and that reserve accumulation has been especially strong in the group of emerging markets.

4.3. Empirical results

In the following section we present and discuss our regression results. All tables contain pairs of regressions: for different country groups they first show the results of the traditional "trilemma" specification that includes indexes for monetary independence, exchange rate stability and capital mobility as explanatory variables. We then compare these results with those of "quadrilemma" regressions that additionally include one of our measures of intervention (see Eq. (17)).

Table 1 presents the results for interventions measured by reserve changes relative to net capital flows. For the full sample, presented in column 1, all three trilemma variables enter highly significant with positive coefficients. The adjusted coefficient of determination lies above 92% in all specifications. In line with Aizenman et al. (2009, 2013) we consider this as evidence that the trilemma is binding and that a trade-off among the three policy variables exists. Column 2 additionally includes our measure for intervention. It yields a negative and significant coefficient on the intensity of interventions: the weighted sum of trilemma variables is the larger, the stronger central banks intervene in response to net capital flows. This is evidence of a relaxed trilemma: interventions are effective in widening the policy space of the trilemma constraint. Conversely, if central bank intervention reinforces private capital flows – the central bank leans with the wind –, $INT^F < 0$ and interventions tighten the trilemma constraint. In this case, the weighted sum of trilemma objectives is lower than without intervention.

We then consider the subsample of industrialised countries. Column 3 shows that the trilemma constraint is equally binding in the industrialised world and, as shown by column 4, may be relaxed by interventions. The remaining regressions present the results for the group of developing and emerging countries as well as for emerging markets and developing countries individually. Based on the results one may conclude that policies in all country groups are constrained by the trilemma. Our "quadrilemma" regressions, however, suggest that interventions enable countries to relax the trilemma. For a given relative intervention intensity, this effect is strongest in emerging markets.

Comparison of the sets of regressions reveals that consideration of interventions does not increase their fit. This shows that the three traditional trilemma variables sufficiently describe the trilemma constraint. Moreover, auxiliary regressions show that exclusion of the index of capital account openness does not significantly lower the fit: for all country groups the R^2 still lies above 0.9. That is to say, the constraint is already present between exchange rate stability and monetary policy independence. The significance of capital account openness and intervention, however, reveals that there are additional trade-offs. In particular, the significance of interventions implies that interventions increase the policy space in the sense that the weighted sum of the other three trilemma variables increases. Interventions are an effective policy instrument. Therefore, our focus is rather on significance than on fit.

To test the robustness of our results we re-run the regressions of Table 1 using INT^P as alternative measure of the degree of exchange market intervention. This index calculates intervention activity as the proportion of exchange market pressure alleviated by exchange market intervention. Although the empirical definition of INT^P differs quite substantially from INT^F, results are robust.

[28] Neely (2000) notes that changes in reserves may be an imperfect proxy for the degree of intervention. Besides interventions, the level of reserves might change due to valuation effects, the payment of foreign government debt by the central bank or discretionary transactions like the allocation of additional SDRs to a country.

[29] The same holds for the sale of reserves when private external debt increases.

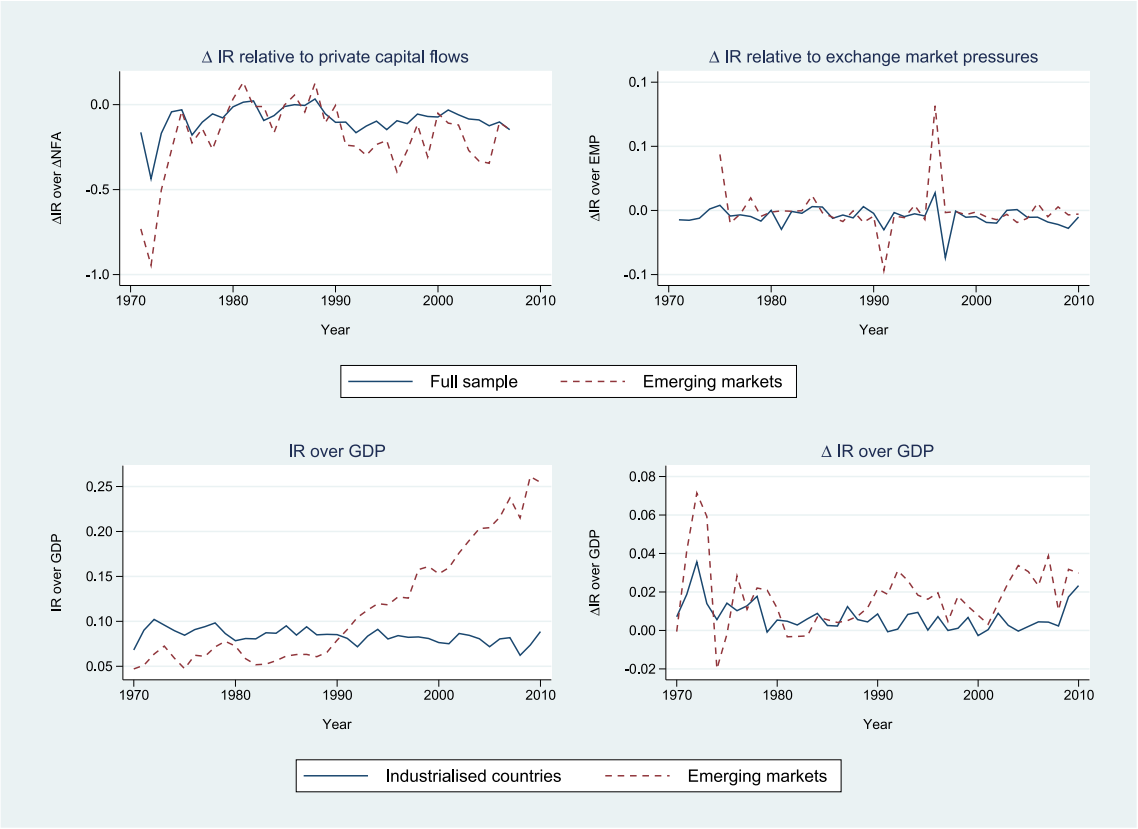

Fig. 4. Measures of exchange market intervention. *Note.* The upper panel of this graph shows the evolution of cross-section averages across time of our two measures of exchange market intervention. The lower panel depicts the cross-country averages of the level of reserves and changes in reserves both relative to GDP. The composition of the respective country groups may be found in Appendix A. IR = international reserves.

Table 1
Trilemma constraint and intervention: reserves and financial flows.

	Full sample		Industrialised countries		Developing and emerging countries		Emerging markets		Developing countries	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Exchange rate stability	0.4380***	0.4584***	0.5550***	0.6063***	0.4181***	0.4425***	0.3923***	0.4092***	0.4286***	0.4549***
	(24.33)	(24.06)	(22.29)	(16.21)	(19.67)	(19.35)	(5.43)	(4.57)	(18.72)	(19.04)
Monetary policy independence	1.1401***	1.1358***	1.1233***	1.1273***	1.2098***	1.1991***	1.3158***	1.3305***	1.1901***	1.1790***
	(33.10)	(33.18)	(17.44)	(16.07)	(30.79)	(29.81)	(13.39)	(11.92)	(27.29)	(26.79)
Capital account openness	0.3811***	0.3778***	0.4418***	0.4027***	0.2834***	0.2798***	0.3903***	0.3612***	0.2651***	0.2584***
	(18.92)	(18.10)	(15.34)	(9.87)	(13.92)	(11.84)	(6.52)	(5.41)	(12.29)	(10.09)
Intervention (ΔIR over ΔNFA)		−0.0338***		−0.0394*		−0.0382***		−0.0734*		−0.0262*
		(−2.63)		(−1.76)		(−2.72)		(−2.07)		(−1.89)
R^2 adjusted	0.95	0.95	0.96	0.96	0.95	0.95	0.93	0.93	0.95	0.95
Observations	3978	2987	758	612	3220	2375	444	367	2813	2039
Number of countries	159	154	23	23	136	131	16	16	121	116

Notes. Robust *t*-statistics are reported in parentheses. Standard errors are estimated robust to intragroup correlations. The symbols *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively. IR stands for international reserves, NFA for net foreign assets.

The findings are presented in Table 2. Intervention activity significantly raises the weighted sum of the trilemma variables in all subsamples. Although both measures of intervention activity are normalised between −1 and +1, the impact coefficient of INT^P is usually larger than that of INT^F.

Both intervention indexes consistently find that the effectiveness of exchange market intervention – measured by the coefficient of the intervention indexes – is relatively large in emerging markets. This may economically explain why this country group intervenes heavily in the market as illustrated by the increase in foreign exchange holdings in this group (see Fig. 4). Emerging market central banks benefit from the fact that they are key players in the foreign exchange market: the size of interventions is relatively large compared to market turnover and bonds outstanding. Moreover, the substitutability of bonds is likely to be lower between emerging markets and industrialised countries than within the industrialised world.

4.4. Robustness

In this section we check the robustness of the results with respect to their stability over time and across different specifications.

Subperiods. It might be interesting to examine whether the effect of exchange market intervention has been stable over time. To this end, we divide the sample into four sub-periods, the first

Table 2
Trilemma constraint and intervention: reserves and exchange market pressure (EMP).

	Full sample		Industrialised countries		Developing and emerging countries		Emerging markets		Developing countries	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Exchange rate stability	0.5458***	0.5473***	0.5771***	0.5784***	0.5108***	0.5129***	0.5473***	0.5475***	0.5149***	0.5182***
	(16.73)	(16.81)	(12.04)	(12.29)	(10.81)	(10.88)	(5.21)	(5.30)	(10.00)	(10.08)
Monetary policy independence	1.0930***	1.0894***	1.0759***	1.0746***	1.1804***	1.1757***	1.2741***	1.2755***	1.1367***	1.1288***
	(30.38)	(30.44)	(15.52)	(15.56)	(24.10)	(24.16)	(12.50)	(12.70)	(20.29)	(20.17)
Capital account openness	0.3901***	0.3890***	0.4367***	0.4350***	0.2880***	0.2867***	0.3551***	0.3528***	0.2709***	0.2697***
	(15.05)	(15.04)	(9.45)	(9.47)	(8.83)	(8.85)	(5.29)	(5.26)	(7.11)	(7.15)
Intervention (ΔIR over EMP)		−0.2876***		−0.3438**		−0.2888***		−0.3388*		−0.3252***
		(−2.98)		(−2.45)		(−2.84)		(−1.82)		(−2.95)
R^2 adjusted	0.95	0.95	0.96	0.96	0.94	0.94	0.93	0.93	0.94	0.95
Observations	1769	1769	664	664	1105	1105	325	325	803	803
Number of countries	97	97	22	22	75	75	14	14	62	62

Notes. Robust *t*-statistics are reported in parentheses. Standard errors are estimated robust to intragroup correlations. The symbols *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively. IR stands for international reserves, NFA for net foreign assets.

Table 3
Robustness across subperiods (1970–1989): reserves and financial flows.

	Full sample		Industrialised countries		Developing and emerging countries		Emerging markets		Developing countries	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1970–1979										
Exchange rate stability	0.3513***	0.4369***	0.4512***	0.5232***	0.3810***	0.5029***	0.4674***	0.5939***	0.3689***	0.4933***
	(8.36)	(8.91)	(7.10)	(5.04)	(7.71)	(7.78)	(4.75)	(5.71)	(6.40)	(6.49)
Monetary policy independence	1.3375***	1.3583***	1.3274***	1.3865***	1.3096***	1.2583***	1.1333***	1.3115***	1.3275***	1.2487***
	(15.67)	(14.31)	(8.74)	(10.54)	(13.28)	(10.00)	(5.72)	(5.78)	(11.68)	(8.78)
Capital account openness	0.3339***	0.3030***	0.4289***	0.3478**	0.1971***	0.1703**	0.4701**	0.3524	0.1835***	0.1565**
	(6.14)	(4.71)	(5.52)	(2.82)	(3.40)	(2.26)	(2.36)	(1.51)	(3.18)	(2.14)
Intervention (ΔIR over ΔNFA)		0.0255		−0.0161		0.0241		0.0996		0.0344
		(0.59)		(−0.20)		(0.48)		(0.81)		(0.68)
R^2 adjusted	0.95	0.94	0.95	0.95	0.96	0.95	0.94	0.92	0.97	0.96
Observations	628	280	168	91	460	189	79	34	390	160
Number of countries	85	79	21	20	64	59	10	10	55	50
1980–1989										
Exchange rate stability	0.3729***	0.3935***	0.6947***	0.7345***	0.3593***	0.3795***	0.2875*	0.2983*	0.3689***	0.3922***
	(10.19)	(10.24)	(8.66)	(8.28)	(8.75)	(8.75)	(1.83)	(1.89)	(8.70)	(8.74)
Monetary policy independence	1.3779***	1.3655***	1.3101***	1.2987***	1.3909***	1.3776***	1.5273***	1.5120***	1.3735***	1.3585***
	(26.86)	(27.28)	(13.16)	(12.41)	(24.01)	(24.24)	(8.31)	(8.21)	(22.53)	(22.91)
Capita account openness	0.2995***	0.3067***	0.2366***	0.2262***	0.2540***	0.2622***	0.2928*	0.3055**	0.2449***	0.2491***
	(7.95)	(7.93)	(3.51)	(3.30)	(5.60)	(5.41)	(2.08)	(2.19)	(4.98)	(4.75)
Intervention (ΔIR over ΔNFA)		0.0137		0.0238		0.0233		0.0918		0.0080
		(0.70)		(0.96)		(0.98)		(1.21)		(0.35)
R^2 adjusted	0.96	0.96	0.97	0.97	0.96	0.96	0.94	0.94	0.96	0.96
Observations	918	824	185	175	733	649	112	112	630	546
Number of countries	120	112	22	21	98	91	14	14	85	78

Notes. Robust *t*-statistics are reported in parentheses. Standard errors are estimated robust to intragroup correlations. The symbols *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively. IR stands for international reserves, NFA for net foreign assets.

ranging from 1970 to 1979 and the last covering the period 2000 to 2010.

Results for the intervention index based on financial flows (INT^F) (see Tables 3 and 4) show that effects differ between periods. For the decades of the 1970s and 1980s interventions do not significantly relax the trilemma constraint. Beginning in the 1990s, interventions have significantly relaxed the trilemma in all subsamples except developing countries during the 1990s.

These pronounced differences between the sample periods might be due to various facts: first, whereas in the first period exchange market interventions are rather singular events in industrialised countries, since the 1990s interventions have increasingly become permanent policies for a group of developing and emerging countries, which follow mercantilist motives independently of crises (see Levy-Yeyati et al., 2013; Pontines and Rajan, 2011). Hence, the nature of interventions has changed. Second, the number of available observations is quite low in the first period, which questions the reliability of the results and which makes it statistically more difficult to establish significant effects.

The finding that central banks' intervention activity has relaxed the trilemma in developing countries since the 1990s, but not in the earlier period, is confirmed by the alternative measure for intervention activity. The only cases where intervention was effective in earlier periods are industrialised countries in the 1970s and developing countries in the 1980s. The results for INF^P using decades as subperiods are presented in Tables 5 and 6.

Alternative empirical approach. As an alternative way to examine the effect of interventions on the trilemma constraint we propose a two-step regression approach: in the first step, we estimate the fitted trilemma value based on its three traditional determinants.

Table 4
Robustness across subperiods (1990–2010): reserves and financial flows.

	Full sample		Industrialised countries		Developing and emerging countries		Emerging markets		Developing countries	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1990–1999										
Exchange rate stability	0.3765***	0.4041***	0.4763***	0.4662***	0.3626***	0.3956***	0.2984***	0.2845***	0.3729***	0.4141***
	(12.07)	(12.08)	(7.62)	(7.57)	(10.29)	(10.41)	(3.29)	(3.39)	(9.94)	(10.26)
Monetary policy independence	1.2237***	1.1841***	0.8868***	0.8325***	1.3214***	1.2868***	1.5037***	1.4531***	1.2960***	1.2560***
	(26.05)	(24.81)	(7.84)	(8.41)	(26.85)	(25.19)	(15.33)	(14.94)	(24.17)	(22.62)
Capital account openness	0.3318***	0.3320***	0.5093***	0.5323***	0.2061***	0.1896***	0.1895**	0.1876**	0.2066***	0.1903***
	(10.99)	(10.32)	(7.75)	(9.14)	(6.03)	(4.99)	(2.37)	(2.26)	(5.56)	(4.51)
Intervention (ΔIR over ΔNFA)		−0.0496**		−0.1425***		−0.0482*		−0.1517**		−0.0186
		(−2.15)		(−3.81)		(−1.88)		(−2.75)		(−0.70)
R^2 adjusted	0.95	0.95	0.97	0.97	0.95	0.95	0.95	0.95	0.95	0.95
Observations	1113	965	187	176	926	789	117	117	818	681
Number of countries	156	145	23	22	133	123	16	16	118	108
2000–2010										
Exchange rate stability	0.5071***	0.5123***	0.3350***	0.3536***	0.5065***	0.5184***	0.6993***	0.6042***	0.5200***	0.5333***
	(23.82)	(22.13)	(3.38)	(3.10)	(20.85)	(19.64)	(4.51)	(3.46)	(20.79)	(20.43)
Monetary policy independence	0.9250***	0.8950***	0.9766***	0.9773***	0.9786***	0.9360***	0.9728***	0.9626***	0.9632***	0.9282***
	(25.21)	(22.79)	(4.00)	(3.72)	(22.33)	(19.74)	(8.14)	(7.06)	(20.09)	(17.94)
Capital account openness	0.4467***	0.4586***	0.6665***	0.6507***	0.3673***	0.3817***	0.5381***	0.5789***	0.3300***	0.3366***
	(19.08)	(17.77)	(6.78)	(5.63)	(13.62)	(12.44)	(5.38)	(5.39)	(11.99)	(10.92)
Intervention (ΔIR over ΔNFA)		−0.0930***		−0.1056*		−0.1019***		−0.1534*		−0.0867***
		(−3.84)		(−1.82)		(−4.13)		(−1.98)		(−3.44)
R^2 adjusted	0.95	0.95	0.98	0.98	0.94	0.95	0.93	0.92	0.95	0.95
Observations	1319	918	218	170	1,101	748	136	104	975	652
Number of countries	158	147	23	23	135	124	16	16	120	109

Notes. Robust *t*-statistics are reported in parentheses. Standard errors are estimated robust to intragroup correlations. The symbols *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively. IR stands for international reserves, NFA for net foreign assets.

Table 5
Robustness across subperiods (1970–1989): reserves and exchange market pressure (EMP).

	Full sample		Industrialised countries		Developing and emerging countries		Emerging markets		Developing countries	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1970–1979										
Exchange rate stability	0.7031***	0.6938***	0.7221***	0.7074***	0.5303	0.4868	0.6736	0.6134	−0.1658*	−0.1715
	(5.76)	(5.75)	(4.27)	(4.21)	(1.51)	(1.36)	(1.48)	(1.21)	(−3.02)	(−1.76)
Monetary policy independence	1.3577***	1.3491***	1.2888***	1.2807***	1.6281***	1.6152***	1.4547***	1.4352***	2.2009***	2.1642***
	(12.02)	(11.89)	(10.31)	(10.36)	(8.60)	(8.13)	(14.11)	(13.53)	(56.29)	(29.65)
Capital account openness	0.2011**	0.2074**	0.2262*	0.2276*	0.4060	0.5570	0.4419	0.6692	0.5661*	0.5280
	(2.37)	(2.51)	(2.13)	(2.14)	(0.46)	(0.61)	(0.38)	(0.51)	(2.74)	(1.85)
Intervention (ΔIR over EMP)		−0.8033***		−1.6975**		−0.7681		−0.7803		−6.2031**
		(−3.62)		(−2.24)		(−1.76)		(−1.24)		(−4.56)
R^2 adjusted	0.95	0.95	0.95	0.95	0.93	0.93	0.91	0.91	0.99	0.99
Observations	115	115	91	91	24	24	15	15	9	9
Number of countries	23	23	15	15	8	8	4	4	4	4
1980–1989										
Exchange rate stability	0.5718***	0.5735***	0.7155***	0.7202***	0.3982***	0.3987***	0.4133*	0.4061*	0.3904***	0.3895***
	(9.72)	(9.74)	(8.01)	(8.36)	(3.92)	(3.92)	(1.97)	(1.93)	(4.93)	(4.82)
Monetary policy independence	1.3417***	1.3397***	1.2179***	1.2147***	1.5429***	1.5423***	1.5458***	1.5492***	1.5477***	1.5456***
	(17.64)	(17.54)	(11.92)	(11.97)	(10.76)	(10.71)	(6.49)	(6.48)	(14.96)	(14.83)
Capital account openness	0.2774***	0.2772***	0.2656***	0.2646***	0.2315	0.2296	0.2277	0.2400	0.2211	0.2170
	(6.09)	(6.06)	(4.21)	(4.16)	(1.36)	(1.35)	(0.67)	(0.70)	(1.34)	(1.34)
Intervention (ΔIR over EMP)		−0.2051		−0.2966		−0.2177		0.6089		−0.8362*
		(−1.17)		(−1.50)		(−0.47)		(0.59)		(−1.81)
R^2 adjusted	0.96	0.96	0.97	0.97	0.95	0.95	0.93	0.93	0.97	0.97
Observations	330	330	182	182	148	148	74	74	77	77
Number of countries	42	42	20	20	22	22	9	9	14	14

Notes. Robust *t*-statistics are reported in parentheses. Standard errors are estimated robust to intragroup correlations. The symbols *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively. IR stands for international reserves, NFA for net foreign assets.

In the second step, we then explain deviations of the fitted trilemma from its expected value. Besides interventions, we include a dummy for currency crises, real GDP as a measure of the stance of development and civil liberties as explanatory variables. Details on the estimation and the results may be found in Appendix D.

Reserves and the trilemma. Besides our measures of intervention relative to market pressures, it might be interesting to examine

Table 6
Robustness across subperiods (1990–2010): reserves and exchange market pressure (EMP).

	Full sample		Industrialised countries		Developing and emerging countries		Emerging markets		Developing countries	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1990–1999										
Exchange rate stability	0.4770***	0.4808***	0.4751***	0.4671***	0.4325***	0.4380***	0.3722***	0.3738***	0.4656***	0.4742***
	(8.30)	(8.41)	(6.49)	(6.68)	(5.03)	(5.12)	(4.19)	(4.30)	(4.30)	(4.39)
Monetary policy independence	1.1387***	1.1345***	0.8592***	0.8567***	1.2960***	1.2905***	1.4326***	1.4357***	1.2291***	1.2180***
	(23.34)	(23.79)	(8.42)	(8.43)	(20.61)	(21.13)	(15.95)	(16.70)	(15.49)	(15.75)
Capital account openness	0.3779***	0.3755***	0.5264***	0.5204***	0.2156***	0.2131***	0.2078***	0.2046**	0.2237***	0.2216***
	(10.25)	(10.20)	(8.26)	(8.26)	(4.21)	(4.17)	(3.09)	(3.02)	(3.72)	(3.73)
Intervention (ΔIR over EMP)		−0.2939**		−1.9745***		−0.2415**		−0.2450*		−0.2951**
		(−2.36)		(−3.47)		(−2.47)		(−1.84)		(−2.59)
R^2 adjusted	0.95	0.95	0.97	0.97	0.95	0.95	0.96	0.96	0.95	0.95
Observations	541	541	204	204	337	337	114	114	233	233
Number of countries	79	79	22	22	57	57	13	13	45	45
2000–2010										
Exchange rate stability	0.5305***	0.5310***	0.3625***	0.3597***	0.5456***	0.5463***	1.0447***	1.0431***	0.5425***	0.5440***
	(14.19)	(14.24)	(3.15)	(3.14)	(11.86)	(11.93)	(5.33)	(5.31)	(12.37)	(12.48)
Monetary policy independence	0.9397***	0.9353***	1.0145***	1.0150***	0.9884***	0.9822***	0.8516***	0.8526***	0.9935***	0.9852***
	(19.94)	(19.78)	(3.98)	(3.99)	(16.04)	(15.99)	(6.08)	(6.04)	(14.34)	(14.18)
Capital account openness	0.4633***	0.4627***	0.6383***	0.6413***	0.3755***	0.3748***	0.4582***	0.4551***	0.3264***	0.3256***
	(13.57)	(13.61)	(5.74)	(5.80)	(9.01)	(9.10)	(3.51)	(3.40)	(7.17)	(7.27)
Intervention (ΔIR over EMP)		−0.2788		0.3997*		−0.3697*		−0.5877		−0.3959*
		(−1.49)		(1.90)		(−1.81)		(−0.45)		(−1.98)
R^2 adjusted	0.94	0.94	0.97	0.97	0.94	0.94	0.94	0.94	0.94	0.94
Observations	783	783	187	187	596	596	122	122	484	484
Number of countries	94	94	21	21	73	73	14	14	60	60

Notes. Robust *t*-statistics are reported in parentheses. Standard errors are estimated robust to intragroup correlations. The symbols *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively. IR stands for international reserves, NFA for net foreign assets.

how a central bank's reserve policy affects the trilemma constraint. In this vein, we replace the intervention variable by the level of reserves relative to GDP or by the change in reserves over GDP and re-run our quadrilemma regressions. Both variables show positive coefficients implying that they negatively affect the degree to which the trilemma goals are achieved (results available upon request). This may be explained by reverse causality given that instabilities drive countries' desire to accumulate reserves.

China. China is the country with the largest absolute increase in international reserves in the recent past. As a result of its massive asymmetric intervention in the foreign exchange market, reserves relative to GDP increased from 1.3% in 1980 to 49% in 2010. China is a vivid example of countries intending to control the trilemma trade-off. In order to assure that our results are not driven by China, we re-run the regressions excluding China. By and large, our qualitative results are confirmed. This is in line with the finding of Aizenman and Sengupta (2013) that capital mobility is not a significant component of the trilemma trade-off in China. Moreover, it supports our hypothesis that foreign exchange interventions loosen the trilemma constraint because they substitute for capital controls.

5. Conclusions

In this paper we demonstrate that the trade-off between the objectives of the macroeconomic trilemma – exchange rate stability, monetary independence and capital mobility – may be relaxed by foreign exchange market interventions. We show in the framework of the portfolio balance model that imperfect asset substitutability allows central banks to steer the exchange rate on the basis of changes in the composition of their balance sheet. We derive a formula for the necessary accumulation of reserves in order to maintain the exchange rate peg in the face of increasing private net foreign assets.

Our empirical analysis of a large panel data set covering the period 1970–2010 explores factors that loosen or constrict the policy space of the trilemma. We find robust evidence that foreign exchange market interventions relax the trilemma constraint when they partly off-set private capital flows. This is to say, the weighted average of trilemma variables is larger when the central bank accumulates reserves in the face of net capital inflows or exchange market pressures. While findings for the period from 1970 to 1989 are weak, the accumulation of reserves has systematically loosened the trilemma constraint since 1990. This effect is especially strong in emerging markets.

These findings entail two major conclusions. First, central banks are able to relax the trilemma trade-off. While this finding is conventional wisdom for the short run – present in the literature on the defence of fixed exchange rates via sales of reserves – our contribution points to the fact that this policy is viable in the medium run alike. In the recent past, exchange market intervention has been the rule rather than the exception: central banks accumulated enormous amounts of reserves. Moreover, this intervention has been asymmetric: it rather absorbed than provided foreign liquidity. Second, we provide an additional explanation for the accumulation of reserves by central banks: it is a by-product of their successful attempt to relax the trilemma constraint. While this argument is linked to the mercantilist motive for reserve accumulation, it has not been examined before.

Nevertheless, it has to be noted that policies that relax the trilemma are a temporary phenomenon. Continuous interventions on the foreign exchange market are limited by a resource constraint: if the central bank sells reserves to defend a pegged exchange rate, this policy can only be implemented until reserves are

exhausted. On the other hand, while the continuous accumulation of reserves as shown by Fig. 4 may continue without limit, it is costly: sterilization of the reserve accumulation causes quasi-fiscal costs if interest paid on domestic assets is higher than interest on reserve assets. Moreover, sterilization is limited by the amount of domestic assets on the central bank's balance sheet. Once all domestic assets are exchanged for reserves, further reserve accumulation may increase the domestic monetary base and potentially cause inflationary pressures.

Our findings are compatible with Rey (2013) who argues that a global financial cycle, which determines capital flows and credit growth, transforms the trilemma into a dilemma: capital flows constrain monetary policy independently of the exchange rate regime. Alike, Devereux and Yetman (2014) show that independently of the exchange rate regime, monetary policy might be constrained by global shocks that drive down interest rates to the zero lower bound. In both settings independent monetary policies require capital controls. This is in line with our finding that capital controls might be replaced by foreign exchange market intervention, which then increases monetary independence and the stability of the exchange rate. Since the effectiveness of capital controls is debated, foreign exchange interventions might even be a more reliable instrument.

We do not address the question of policy optimality and leave it for future research instead. While a relaxed trilemma offers domestic policymakers some flexibility, their leaning against the trilemma constraint is costly and may be detrimental to the development of domestic financial markets. More recently, a growing literature questions the desirability of capital mobility and considers flexible capital controls as a prudential policy tool to reduce financial fragility (see, among others, Farhi and Werning (2014) and Ostry et al. (2012)).

Appendix A. Sample of countries

Albania	Djibouti	Lao PDR	Rwanda
Angola	Dominica	Latvia	Sao Tome and Principe
Antigua and Barbuda	Dominican Republic	Lebanon	Saudi Arabia
Argentina[b]	Ecuador	Lesotho	Senegal
Armenia	Egypt, Arab Rep.[b]	Liberia	Seychelles
Aruba	El Salvador	Libya	Sierra Leone
Australia[a]	Equatorial Guinea	Lithuania	Singapore
Austria[a]	Estonia	Madagascar	Slovak Republic
Azerbaijan	Ethiopia	Malaysia[b]	Slovenia
Bahamas	Fiji	Maldives	Solomon Islands
Bahrain	Finland[a]	Mali	Spain[a]
Bangladesh	France[a]	Malta[a]	Sri Lanka
Barbados	Gabon	Mauritania	St. Kitts and Nevis
Belarus	Gambia, The	Mauritius	St. Lucia
Belgium[a]	Georgia	Mexico[b]	St. Vincent and the Grenadines
Belize	Germany[a]	Micronesia	Sudan
Benin	Ghana	Moldova	Suriname
Bhutan	Greece[a]	Mongolia	Swaziland
Bolivia	Grenada	Morocco	Sweden[a]
Botswana	Guatemala	Mozambique	Switzerland[a]
Brazil[b]	Guinea-Bissau	Myanmar	Syrian, Arab Republic
Bulgaria	Guyana	Nepal	Tajikistan
Burundi	Haiti	Netherlands[a]	Tanzania
Cambodia	Honduras	New Zealand[a]	Thailand[b]
Cameroon	Hong Kong	Nicaragua	Togo
Canada[a]	Iceland[a]	Niger	Tonga
Cape Verde	India	Nigeria	Trinidad and Tobago
Central African Republic	Indonesia[b]	Norway[a]	Tunisia
Chad	Iran, Islamic Rep.	Oman	Turkey
Chile[b]	Ireland y[a]	Pakistan	Uganda
China[b]	Israel[b]	Panama	Ukraine
Colombia	Italy[a]	Papua New Guinea	United Kingdom[a]
Congo, Dem. Rep.	Jamaica	Paraguay	Uruguay
Congo, Rep.	Japan[a]	Peru[b]	Vanuatu
Costa Rica	Jordan	Philippines[b]	Venezuela, RB
Cote d'Ivoire	Kazakhstan	Poland[b]	Vietnam
Croatia	Kenya	Portugal[a]	Yemen, Rep.
Cyprus	Korea, Rep.[b]	Qatar	Zambia
Czech Republic	Kuwait	Romania	Zimbabwe
Denmark[a]	Kyrgyz Republic	Russian Federation[b]	

Notes. Countries that belong to the group of industrialised countries are marked by the index *a*. Classification is in line with the IMF classification in its International Financial Statistics. The group of emerging market economies is marked by the index *b*.

Appendix B. List of variables and data sources

Variable	Source	Definition
Trilemma indexes	Aizenman et al. (2009, 2010, 2013)	The trilemma indexes consist of three individual indexes: a monetary independence index, an index of exchange rate stability and a measure of capital mobility. The indexes are normalised between 0 and 1. Higher index values indicate that policy is closer to the respective objective
Reserve assets	IFS (2015)	Net flows of reserve assets are derived from the balance of payments. Data from the Balance of Payments Manual 5 (BOPM5) are combined with those from the Balance of Payments Manuel 6 (BOPM6). Data are annually and in current U.S. dollars
Private net foreign assets	Lane and Milesi-Ferretti (2007) and update	Total external assets minus total external liabilities minus reserves
Capital controls	Chinn and Ito (2006) and update	Measure of the de jure openness of the capital account (kaopen). Calculation is based on the binary dummy variable of the IMF's Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER)
Currency crisis, dummy	Reinhart and Rogoff (2011)	Currency crises are defined as periods in which annual exchange rate depreciations exceed a threshold of 15%
Real GDP per capita	WDI (2012)	GDP is measured as gross domestic product in constant international dollars with the year 2000 as base. An international dollar has the same purchasing power over GDP as the U.S. dollar has in the United States. This measure of GDP is divided by the population which counts all residents regardless of legal status or citizenship
Exchange market pressure index (quarterly data)		
Nominal exchange rate	IFS (2012)	National currency per U.S. Dollar, end of quarter
Money market rate	IFS (2012)	Rate on short-term lending between financial institutions (line 60b)
Lending rate	IFS (2012)	Bank rate for short- and medium-term loans to the private sector (line 60p)
Reserve assets	IFS (2012)	Net flows of reserve assets are derived from the balance of payments. Data from the Balance of Payments Manual 5 (BOPM5) are combined with those from the Balance of Payments Manuel 6 (BOPM6). Data are quarterly and in current U.S. dollars

Sources: IFS: International Financial Statistics; WDI: World Development Indicators.

Appendix C. Measurement of intervention

This appendix presents additional details concerning the construction and interpretation of our indexes of exchange market intervention.

C.1. Reserve changes relative to private capital flows

Data on private net foreign assets is derived from Lane and Milesi-Ferretti (2007, and update). Net foreign assets are calculated as the difference between assets and liabilities. Assets (liabilities) are the sum of FDI, portfolio equity, debt and financial derivatives assets (liabilities). Assets normally also include central banks' stocks of international reserves. Since we are interested in *private* net foreign assets, we do not include them in our measure. The change in NFA is our measure of wealth transfer between countries.

For $0 < INT^F < 1$ the central bank partly offsets the missing demand for foreign assets. $INT^F < 0$, in turn, implies that the central bank reinforces the change in the relative demand for both assets. $INT^F > 1$ presents an extreme form of leaning against the wind: in the case of decreasing private demand for foreign assets the central bank intervention more than offsets the shortfall and contributes to an increase in the gross demand for foreign assets.

C.2. Reserve changes relative to exchange market pressure

This approach is based on the exchange market pressure index (EMPI) provided by Eichengreen et al. (1996). A disequilibrium on the foreign exchange market characterised by an excess demand for the other country's currency may be met through various channels: the currency may be devalued, the central bank may sell reserves or monetary policy may accommodate pressures by raising interest rates.[30] Accordingly, the EMPI is defined as the weighted sum of exchange rate changes, reserve changes and interest rate changes relative to the US as reference country:

$$EMPI_{it} = \frac{1}{\sigma_i^E}\frac{\Delta E_{it}}{E_{it}} - \frac{1}{\sigma_i^{IR}}\frac{\Delta IR_{it}}{IR_{it}} + \frac{1}{\sigma_i^i}\Delta(i_{it} - i_{US,t}) \tag{20}$$

where the variable i is the nominal interest rate.[31] The standard deviation σ is calculated individually for each country over the whole period. E is defined relative to the US dollar.

Since annual observations may lack the necessary precision[32], the EMPI is calculated on the basis of an additional data set, which contains quarterly observations of the relevant variables (international reserves, nominal exchange rate and interest rate).[33] To transform these quarterly observations to annual ones, the means of EMPI and the weighted change in IR (see Eq. (19)) are calculated for any given year.

The intervention index lies between ∞ and $-\infty$. When the exchange rate flows freely $INT^P = 0$. When, in turn, the central bank stabilizes the exchange rate solely by exchange market intervention $INT^P = 1$. Intermediate exchange rate systems are characterised by

[30] The opposite holds for an excess demand for domestic currency.

[31] An alternative definition of EMPI discards interest rate effects (e.g. Aizenman and Pasricha, 2013). We prefer to include the effects of monetary policy: while an increase in interest rates might alleviate pressures on the exchange rate and/or reserves, the deviation of monetary policy from global liquidity conditions implies that it affects capital flows and thereby is a response to pressures on the exchange rate.

[32] A constant level of reserves on a year-to-year basis may disguise a sharp reserve loss followed by reserve restocking.

[33] Given that reserve flows are not reported on a monthly basis, we cannot use monthly data.

$0 < INT^P < 1$. Negative values of INT^P are the result of an intervention policy that magnifies the exchange rate change induced by private capital flows. This policy may be labelled "leaning with the wind" (see Weymark, 1995). At the other extreme, when $INT^P > 1$, exchange market intervention more than offsets privately induced exchange market pressures. In this case the central bank depreciates (appreciates) the domestic currency although there is an excess demand (supply) for domestic currency in the private market.

As an example assume that interest rates and exchange rates are stable. Exchange market pressures stem exclusively from changes in reserves and our measure for the degree of intervention equals one. In this case, the central bank buffers pressures entirely and avoids an exchange rate adjustment. The trilemma constraint is relaxed. Conversely, if for given exchange market pressures reserves are held constant, the buffering effect – and our measure for intervention – is zero and we expect that the trilemma holds strictly.

To make both intervention indexes comparable to the three trilemma indexes, we normalise INT^F and INT^P between −1 and +1.

Appendix D. Two-step regression approach

As a robustness test whether changes in reserves relax the trilemma, this Appendix presents an alternative regression approach: we examine whether deviations of the fitted trilemma variable from its expected value may be explained by the intensity of foreign exchange market interventions. To this end, we follow a two-step approach: alike Aizenman et al. (2009, 2013) we first regress the constant one on the three trilemma variables:

$$1 = \alpha ERS_{it} + \beta MI_{it} + \gamma KAOPEN_{it} + e_{it} \tag{21}$$

where *ERS* controls for the stability of the exchange rate, *MI* is the measure of the independence of monetary policy and *KAOPEN* accounts for the de jure openness of the capital account.

While the fit indicates that the trilemma holds in the long run, a good fit is compatible with deviations from the linear restriction in individual years. Using the estimated coefficients we calculate the predicted values of the trilemma variable. Given the regression design, the expected value of the weighted sum of the three trilemma variables equals one. If the predicted value is smaller than one, the constraint is not binding. An example is a country with fixed exchange rate and capital controls whose monetary policy is less independent than what would be feasible. If, in turn, the predicted value is larger than one, the trilemma objectives are "overfulfilled". The value of one trilemma variable is too high given the other two trilemma components. One might think of a situation with fixed exchange rate and capital mobility where monetary policy has preserved some leeway. In line with our theoretical exposition, we argue that this configuration might be the result of exchange market interventions.

While the first-step regression examines whether the trilemma constraint holds in the long run, the second step focuses on short-run deviations. To this end, we regress the fitted value of the trilemma index[34] on possible determinants of the strictness of the trilemma constraint: a measure of exchange market intervention, a dummy variable for currency crises and real GDP per capita as a measure of the stance of development.

During crises and periods of financial stress, countries might be unable to fully exploit the trilemma policy space. The leeway within the trilemma might be more constrained than in normal circumstances. The country may achieve only one trilemma variable. Hence, we expect a negative effect of currency crises on the fitted trilemma value.

In addition, the flexibility of choices within the trilemma space might depend on a country's stance of development. Compared to industrialised countries the trade-off among trilemma variables in less developed countries might be less favourable in the sense that a move towards one trilemma variable is associated with a larger reduction in the other two trilemma variables. As an example, for given exchange rate regime and capital controls capital flows to less developed countries might be more sensitive to interest rate changes.

In particular, we estimate the following relationship

$$\widehat{Trilemma}_{it} = \delta X_{it} + \theta INT_{it} + {}_{it} \tag{22}$$

where $\overline{Trilemma}$ are the predicted values of the trilemma variable from the first-step regression, X is a vector of control variables, *INT* a measure of exchange market intervention and ε is the error term. i denotes a specific country and t represents the time period. The slope parameters, represented by the vectors δ and θ, are assumed to be constant across countries and time. We use the pooled regression model with a cluster-robust variance estimator.

Due to the two-step procedure, the estimates of δ and θ are biased and underestimated if X and *INT* are correlated with the trilemma indexes (exogenous variables in the first step). Since the t-test results more conservative than in the one-step procedure, significance in the two-step procedure implies significance in the one-step approach (see Freund et al., 1961). Moreover, Wallace (1964) shows that the stepwise estimator may outperform the least squares approach if both methods are compared by the mean square error criterion. Since the magnitude of coefficients is difficult to interpret, our discussion of results focuses on their significance and sign.

D.1. Empirical results

Our presentation of results focuses on the second step, namely regressions of the fitted trilemma variable on possible determinants. Results of the first step are included in Tables 1 and 2.

We first present results for interventions measured by reserve changes relative to net capital flows. When we regress the fitted trilemma values on INT^F, the effects mostly turn out to be insignificant. We suspect that this might be due to asymmetric effects of interventions: as described above, exchange market interventions during financial stress and impending crises might postpone a devaluation and smooth the effects of crises. They are, however, unable to relax the trilemma since the trilemma trade-offs are less flexible during times of economic stress. Exchange market interventions might rather relax the trilemma when they are pursued during normal times in the face of increasing net foreign assets. We therefore construct a modified intervention measure that only accounts for interventions when net foreign assets increase ($\Delta NFA > 0$).

Table D.1 presents the results for different country groups and specifications. For the full sample, the bivariate regression of the fitted trilemma variable on INT^F yields a positive and significant coefficient: the weighted sum of trilemma variables is the larger, the stronger central banks respond to net capital inflows. This is evidence of a relaxed trilemma. Column 2 adds a dummy for currency crises as control. During crises the weighted sum of trilemma variables is significantly lower than during normal times. That is to say, the trilemma trade-offs shrink during crises. Real GDP per capita, which is added in column 3, does not significantly affect the trilemma while the effects of interventions and crises are robust to the inclusion of this additional regressor. Columns 6 and 7 report similar results for the group of emerging and developing countries. Yet, findings for industrialised countries differ (re-

[34] This procedure is equivalent to using the residuals of the first-step regression – multiplied by minus one – as dependent variable in the second step.

Table D.1
Intensity of the trilemma constraint: reserves and financial flows. Dependent variable: deviation from trilemma constraint.

	Full sample			Industrialised countries		Developing and emerging countries		Emerging markets	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Intervention (ΔIR over ΔNFA)	0.1317**	0.1745*	0.1642*	−0.0110	−0.0688	0.1427**	0.1426*	0.3230***	0.3037***
	(2.28)	(1.99)	(1.96)	(−0.11)	(−0.25)	(2.24)	(2.01)	(4.11)	(3.71)
Currency crisis, dummy		−0.1334***	−0.1440***		−0.1032***		−0.1566***		−0.1089**
		(−5.11)	(−5.00)		(−4.03)		(−3.77)		(−2.26)
Real GDP per capita			0.0015		0.0037		0.0013		−0.0433***
			(−1.18)		(1.51)		(0.42)		(−3.76)
R^2 adjusted	0.00	0.06	0.07	0.00	0.07	0.00	0.11	0.04	0.10
Number of countries	153	66	65	24	22	129	43	19	17
Number of observations	1147	463	461	297	237	877	224	122	68

Notes. Robust *t*-statistics are reported in parentheses. Standard errors are estimated robust to intragroup correlations. The symbols *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively.

Table D.2
Intensity of the trilemma constraint: reserves and exchange market pressure (EMP). Dependent variable: deviation from trilemma constraint.

	Full sample			Industrialised countries		Developing and emerging countries		Emerging markets	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Intervention (ΔIR over EMP)	0.1338*	0.3061**	0.3035**	0.2851**	0.2773	0.1065	0.3274**	0.4159**	0.5458**
	(1.71)	(2.06)	(2.07)	(1.23)	(1.17)	(1.31)	(2.50)	(1.99)	(2.35)
Currency crisis, dummy		−0.1502***	−0.1567***		−0.1254***		−0.1521***		−0.1098***
		(−8.54)	(−8.66)		(−4.47)		(−6.55)		(−3.04)
Real GDP per capita			0.0014**		0.0033***		0.0041**		0.0001
			(−2.47)		(3.07)		(2.43)		(0.01)
R^2 adjusted	0.00	0.06	0.06	0.00	0.07	0.00	0.07	0.01	0.05
Number of countries	147	65	64	24	22	123	42	19	17
Number of observations	2655	1174	1170	677	538	1978	632	455	284

Notes. Robust *t*-statistics are reported in parentheses. Standard errors are estimated robust to intragroup correlations. The symbols *, ** and *** denote statistical significance at the 10%, 5% and 1% levels, respectively.

ported in columns 4 and 5): interventions do not affect trilemma trade-offs in advanced countries. The reason might be that industrialised countries have more stable trilemma configurations and engage less in interventions. The mean of INT^F over the full sample is 0.016, whereas it amounts to 0.005 in industrialised countries. So empirically, interventions in the industrialised world might be too small to affect the trilemma. In emerging markets (columns 8 and 9) trilemma trade-offs are more flexible than in the rest of the world: the effect of interventions is twice as large as in the full sample. Currency crises again move countries away from the trilemma objectives. Real GDP per capita significantly reduces the trilemma variable in emerging markets. More developed countries do not fully exhaust the trilemma policy space.

To test the robustness of our results we re-run the regressions of Table D.1 using INT^P as alternative measure of the degree of exchange market intervention. The findings, which are presented in Table D.2 , are robust to this alternative variation. In the bivariate regressions, intervention activity significantly raises the weighted sum of the trilemma variables except for the group of developing and emerging markets. The insignificant effect in the latter group might be due to the omission of currency crises. Currency crises are expected to lower the trilemma variable, that is, are associated with a lower accessibility of the trilemma objectives. Since this group suffered from crises with some regularity, the positive effect of intervention activity and the negative effect of currency crises – where intervention activity is relatively high – might cancel out. This suspicion is confirmed by the regression in column 7. After controlling for currency crises and real GDP per capita intervention activity raises the trilemma variable significantly in the group of emerging and developing countries. This also holds for the other country groups except industrialised countries. Currency crises reduce the accessibility of the trilemma objectives across all specifications. With the exception of emerging markets, the stance of development is positively associated with the trilemma variables. More developed countries are able to reach higher combinations of the three trilemma dimensions.

The low R^2 in the bivariate regressions indicates that exchange market interventions cannot explain the variation of the trilemma constraint across countries and over time. There exist other factors that determine its flexibility. It would, however, be erroneous to conclude that interventions are ineffective. On the contrary, the statistical and economic significance of interventions shows that they are a powerful instrument to relax the trilemma.

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