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Exchange market pressure: an evaluation using extreme value theory

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Abstract: This thesis discusses the phenomenon of currency crises, in particular it is devoted to empirical identification of crisis periods. As a crisis indicator, we aim to utilize an exchange market pressure index which has been revealed as a very powerful tool for the exchange market pressure quantification. Since enumeration of the exchange market pressure index is crucial for further analysis, we pay special attention to different approaches of its construction. In the majority of existing literature on exchange market pressure models, a currency crisis is defined as a period of time when the exchange market pressure index exceeds a predetermined level. In contrast to this, we incorporate a probabilistic approach using the extreme value theory. Our goal is to prove that stochastic methods are more accurate, in other words they are more reliable instruments for crisis identification. We illustrate the application of the proposed method on a selected sample of four central European countries over the period 1993 - 2012, or 1993 - 2008 respectively, namely the Czech Republic, Hungary, Poland and Slovakia. The choice of the sample is motivated by the fact that these countries underwent transition reforms to market economies at the beginning of 1990s and therefore could have been exposed to speculative attacks on their newly arisen currencies. These countries are often assumed to be relatively homogeneous group of countries at similar stage of the integration process. Thus, a resembling development of exchange market pressure, particularly during the last third of the estimation period, would not be surprising.

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1. Introduction

Last decades experienced a large number of currency crises in variously developed market economies, independently of their exchange rate regime. Most recently, we observed especially dramatic developments in the years from 2009 to 2011 as consequences of global financial crisis. These financial crises have had devastating economic, social, and political consequences, mainly in emerging market economies. As a result, scholars and policymakers have intensified their efforts to understand the causes and early symptoms of financial crises.

In this thesis, we examine the determinants of the market movements in exchange rates by focusing on the exchange market pressure index. The exchange market pressure measures the extent of exchange rate developments in terms of actual depreciations while controlling for policy actions brought about by changes in international reserves and interest rates. Monitoring of an index and exchange markets is important from the perspective of a monetary authority. Countries under a fixed exchange rate regime have to maintain the central exchange rate parity and act in the foreign exchange market accordingly. On the other hand, open economies following the inflation targeting strategy use exchange rate as one of the factors included in models forecasting domestic inflation. Therefore, monitoring of the foreign exchange market is crucial for successful and effective monetary policy. First, for countries that pursue a fixed exchange rate regime, exchange rate stability is a direct target. Second, exchange rate developments tend to have a sizable effect on the inflation outlook and therefore on price stability. The importance of monitoring the exchange market pressure is also reflected in the fact that it is one of five components that the International Monetary Fund uses to measure financial stress. Moreover, exchange market pressure indexes are also used to assess a country's readiness to adopt a common currency.

The analysis of shocks to foreign exchange markets was firstly surveyed in 1977 (Girton and Roper (1977)). The feature of generality of the first model was substantially modified since then. Later authors focused on the determinants of exchange market pressures and found out, for instance, that market pressures are strongly related to the underlying financial structure such as the level of capital controls and the development of financial markets. Whereas some empirical papers are focused straight on estimation of exchange market pressure in a variety of regions and countries, other studies use the exchange market pressure measure as an element of a subsequent analysis examining currency crises, monetary policy, foreign exchange intervention, exchange rate regime and other issues. In this thesis we are mainly concerned with those discussing currency crisis identification.

Our aim is to utilize exchange market pressure index in order to distinguish cur-

rency crisis periods. Large values of the index are generally indicative of currency crisis periods. The majority of papers focusing on currency crisis identification uses very simple deterministic decision rule, as soon as the value exceeds a predetermined threshold, the period is marked as currency crisis. However we conjecture that the choice of the optimal threshold can be a treasonable issue. It is well known that financial series are more likely compatible with heavy-tailed distributions. Therefore in this thesis we use extreme value theory to identify extreme values for exchange market pressure. One of the main arguments mentioned by several authors is that the tail of the distribution of exchange market pressure constitutes its outliers, which are the results of successful and unsuccessful pressures against the currency, i. e., currency crisis periods. A good indicator for the mass in the tails is the tail index corresponding to the fitted generalized extreme value distribution.

Despite a great popularity of exchange market pressure one can find a very limited number of studies focused on central European countries founded after disintegration of the Soviet Union. Our analysis is focused on four countries, the Czech Republic, Hungary, Poland and Slovakia, which joined the European Union in the spring of 2004. The need for analysis in this region should gain even more urgency if we take into account the current process of monetary integration in European Monetary Union since euro implementation is dependent on the fulfillment of several convergence criteria, which also include criterion of national currency's stability in the period preceding entry into the euro area. This criterion is associated with specific exchange rate regime, European Exchange Rate Mechanism II, which must be adapted by all countries with regimes whose principles do not correspond with the ERM II's spirit, i.e., crawling pegs, free floats or managed floats without a mutually agreed central rate and pegs to anchors other than the euro. The Czech Republic, Hungary and Poland currently use flexible exchange rate arrangements. Slovakia, on the other hand, changed a flexible regime to a peg when entering into the European Exchange Rate Mechanism II in November. Such a change toward a less flexible exchange rate system could increase susceptibility of the countries to currency crises and pressures in foreign exchange markets. We tend to estimate exchange market pressure in the Czech Republic, Hungary, Poland and Slovakia over the period of 20 years (January 1993 - December 2012), or 16 years (January 1993 - December 2008) in the case of Slovakia which became a member of European Monetary Union in January 2009. Consequently, we judge whether these states faced to excessive exchange market pressure that could pose a threat to fulfillment of the exchange rate stability criterion. We apply alternative method utilizing extreme value theory for identification of these excessive values that are considered as currency crisis periods. Since all countries applied both a fixed and flexible exchange rate regime, the time span chosen allows us to compare magnitude of tensions in the foreign exchange market in different exchange rate environments. This kind of analysis has important policy implications as Slovakia has already adopted euro and the

remaining countries will make this unavoidable step in the near future.

The remainder of the thesis is organized as follows. The first chapter defines currency crisis as economic phenomenon and consequently discuss its features and results. Moreover, the chapter provides a brief introduction to models of currency crisis formation. In Chapter 3 we state a general definition of exchange market pressure. In the following part we trace history of exchange market pressure index developed by this time and focus on different assumptions and different starting points proposed by various authors, we mainly tend to discuss in detail model dependent and model independent approach with special emphasis on critical assessment of proposed models. As a result we intent to determine the most suitable construction of the exchange market pressure index for further analysis. In addition, we explain utilization of the index when identifying currency crisis periods, which also includes recently proposed method using the extreme value theory. Chapter 4 is rather theoretical and right after a brief introduction to the extreme value theory, it introduces the cornerstone of the theory, the Extremal Types Theorem. Behaviour of an event can be precisely described by its statistical distribution, which is uniquely determined by a several parameters. In order to estimate these parameters, the Hill method is introduced in this chapter and in Appendix A we provide the exact mathematical derivation. Chapter 5 summarizes computational experience carried on the database sample. In the first step, a series of exchange market pressure indices is computed for the selected sample of countries. In the second step, we attempt to apply the Hill method in order to identify the currency crises. In addition to this, we explore dependence of the exchange market pressure index value on country characteristics. Once the crisis is statistically defined for a particular country and particular period, we are interested whether any evidence in the behaviour of economic subjects is observable. Chapter 6 concludes obtained results and testify the efficiency of statistical identification of currency crises.

2. Currency crisis

A currency crisis can be defined as a speculative attack on a foreign exchange value of currency that either results in a sharp depreciation or forces the authorities to defend the currency by selling foreign exchange reserves or raising domestic interest rates. For an economy with a fixed exchange rate regime, a currency crisis usually refers to a situation in which the economy is under pressure to give up the prevailing exchange rate peg or regime. In a successful attack the currency depreciates, while an unsuccessful attack may leave the exchange rate unchanged, but at the cost of spent foreign exchange reserves or higher domestic interest rates. A speculative attack often leads to a sharp exchange rate depreciation despite a strong policy response to defend the currency value.

Currency crises have always been a feature of the international monetary system, both during the Bretton Woods system of generalized fixed parities among major industrialized countries in the postwar period as well as after its breakdown in the early 1970s. The 1990s witnessed many episodes of currency turmoil, most notably the near breakdown of the European Exchange Rate Mechanism in 1992 - 1993, the Latin American Tequila Crisis following Mexico's peso devaluation in 1994 - 1995, the severe crisis that swept through Asia in 1997 and 1998, and more recently, the global financial crisis struck in 2008 that forced sharp depreciations in many advanced as well as developing economies (for detailed discussion on these currency crisis we refer to Krugman (2007)).

The ability of countries to maintain commitments to particular exchange rate targets became increasingly more difficult with increasing global financial integration and capital mobility over time. According to the principle of the impossible trinity in international economics, a country cannot simultaneously have a fixed or managed exchange rate, and an independent domestic monetary policy, when capital is freely mobile. When capital mobility is high and a country pegs its exchange rate to another country's currency, its domestic interest rates are linked to foreign interest rates, which severely limits its ability to pursue an independent domestic monetary policy. The constraint imposed by the trinity was tested most dramatically by the three major currency crises of the 1990s mentioned above (the speculative attack on the European Monetary System, the Mexican peso crisis, and the Asia crisis).

In principle, countries with floating exchange rates should be more resistant to currency crises, since one would expect continuous market adjustment to limit the buildup of pressures leading to extreme currency overvaluation and subsequent large discrete currency declines as may occur under fixed exchange rate regimes. In fact, pegged and intermediate exchange rate regimes are associated with greater susceptibility to currency crises, as well as other financial crises,

such as debt crises, sudden stops in capital inflows, and banking crises. Nonetheless, many countries purportedly with floating exchange rates have experienced currency crises. According to some authors, this can be attributed to the fact that although these countries report their currencies as on a floating rate regime, they often follow a pegged exchange rate regime due to so-called fear of floating behaviour.

Remark 1. (On currency crisis definitions and measurement issues). Different definitions of currency crisis have been used in the empirical literature. Some papers use a narrow definition of crisis, i.e., a successful attack that results in a significant depreciation of the exchange rate. For example, Frankel and Rose (1996) define a currency crisis as a nominal depreciation of 25% or greater, which is at least 10% greater than the depreciation in the preceding year. To avoid capturing the large exchange rate fluctuations associated with high inflation periods, Milesi Ferretti and Razin (1998) use a definition that requires, in addition to a 25% depreciation, at least a doubling in the rate of depreciation with respect to the previous year and a rate of depreciation the previous year below 40%. Other papers use a broader definition that includes episodes of unsuccessful attacks as captured by large changes in an index of exchange market pressure, defined as a weighted average of exchange rate changes, domestic credit changes and reserve losses (these model are discussed in detail in the following chapter). Changes in the index above some threshold are deemed to represent crises, defined as a zero-one binary variable. The threshold is usually defined in terms of country specific moments, usually on the basis of statistical approach. The following chapter is devoted to detailed discussion of these models.

2.1 Currency crisis models

To advance the discussion of currency crises, this section presents a summary of the currency crises models broadly discussed, for instance, in Glick and Hutchison (2011) or Pesenti and Tille (2000). We begin by discussing the so-called first generation models, in which crises are viewed in the literature as the unavoidable result of unsustainable policies or fundamental imbalances. Next, we survey the second generation of models, which highlights the possibility of self-fulfilling exchange rate crises. We also shortly mention the most recent third generation models, which assign causes of currency crisis to distortions in financial markets and banking systems.

2.1.1 First generation models

The first generation models, see for example Krugman (1979), view a currency crisis as the unavoidable outcome of unsustainable policy stances or structural

imbalances, in particular the exchange rate regime is a component of a broader policy package, and the regime can be sustained only if it does not conflict with other monetary and fiscal objectives. In other words, the first generation models focus on inconsistencies between domestic macroeconomic policies and a persistent government budget deficit that eventually must be monetized.

Consider a country with an expansionary monetary policy and a fixed exchange rate. In this economy, the defense of the exchange rate peg will lead to a depletion of foreign reserves held by the domestic central bank. More precisely, the rate of domestic credit expansion is bound to exceed the growth in demand for the domestic currency. Agents who are accumulating excess liquidity prefer to exchange domestic currency for foreign denominated securities or domestic interest bearing assets. Both scenarios lead to a depreciation of the domestic currency. In the former case, pressures stem directly from increased demand for foreign securities. In the latter, domestic bond prices will rise and their yields will fall, leading market participants to sell domestic securities and buy higher yielding foreign assets. Since the domestic central bank is committed to keeping the exchange rate fixed, it must accommodate the increased demand for foreign currency by reducing its foreign reserves. In sum, the process of domestic credit expansion translates into a loss of reserves.

At first glance, one would expect the stock of foreign reserves to fall over time. When the reserves are exhausted, the central bank would have no choice but to let the domestic currency float. A key insight of the first generation model, however, is that the exhaustion of reserves takes the form of a sudden depletion, instead of a gradual running down of the stock. Acting in anticipation of an exchange rate depreciation, market participants liquidate their domestic currency holdings while the stock of foreign reserves held by the central bank is still relatively large. In the context of this model, a currency crisis takes the form of a speculative attack and a stock shift portfolio reshuffling occurs as soon as agents can confidently expect a non negative return on speculation. In such a crisis scenario, agents buy the entire stock of foreign reserves that the central bank is willing to commit to defend the fixed exchange rate. In the aftermath of the speculative attack, the central bank is forced to float the currency.

It is easy to interpret this exogenous policy model in terms of an inconsistency between a fixed exchange rate regime and domestic fiscal imbalances. In fact, the credit expansion described above can be thought of as the result of a fiscal deficit monetization by the central bank. From this vantage point, we see that the model shows that fiscal imbalances directly contribute to a country's vulnerability to currency crises and speculative attacks.

2.1.2 Second generation models

Unlike first generation models, which assume that an exchange rate peg is determined by exogenous fundamentals and market participants base their expectations on the presumption that their actions will not affect fiscal imbalances or domestic credit policies, the second generation models, best represented by Obstfeld (1986), assume that market expectations directly influence macroeconomic policy decisions. Such models are also referred to as the endogenous policy approach, since policymakers' actions in these models represent optimal responses to macroeconomic shocks.

Consider a country whose monetary authorities are committed to maintaining the exchange rate peg, but are willing to float their currency under extraordinary circumstances such as a sharp cyclical downturn. If the country's loans from abroad were denominated in the borrowing nation's domestic currency, foreign investors would face the possibility of a devaluation of the currency, which would reduce the value of their claims. If foreign investors considered the possibility of a devaluation to be very likely, they would charge a high risk premium on their loans. The country's borrowing costs would rise significantly, reducing credit opportunities and curtailing output growth. The country's authorities would then deem the costs of maintaining the peg to be too high and choose to devalue their currency to boost aggregate demand and employment. The devaluation, in turn, would validate the initial investors' expectations. Thus, expectations of devaluation lead to actions that raise the opportunity cost of defending the fixed parity. Therefore, the forecasts force a policy response (the abandonment of the peg) that validates the original expectations. Conversely, consider an alternative scenario in which investors do not forecast any devaluation and do not charge any risk premium. In this case, borrowing costs would remain low and the authorities could maintain the exchange rate peg, thereby validating the expectations of no devaluation. A currency crisis can be thought of as a shift in expectations toward the devaluation outcome. Such a shift suddenly makes the defense of the peg excessively costly.

The main advantage of resorting to such an interpretation of currency crises is the ability to distinguish between two kinds of volatility, one related to financial markets and one related to macroeconomic fundamentals. The former volatility substantially exceeds the latter, market sentiment, in the form of sudden and arbitrary changes in market participants' expectations, plays a prominent role in the determination of a crisis. These models, however, do not explain what causes the shifts in private agents' expectations. In other words, the theory remains silent on the determinants of the losses of confidence that are the cornerstone of the analysis.

Remark 2. (On third-generation models). Third-generation models generally focus on how distortions in financial markets and banking systems can lead to cur-

rency crises. Different third generation models offer various mechanisms through which these distortions work, for instance, some models see causes of crisis in financial liberalization and government guarantees of private sector liabilities which generate moral hazard and unsustainable fiscal deficits, other models emphasize the possibility of self-fulfilling international liquidity crises in an open economy with unrestricted capital markets in which banks issue deposits in domestic and foreign assets, but have longer term illiquid investments that cannot be readily converted to cash in event of a bank run.

2.2 Features and effects of currency crisis

The theoretical and empirical literature has identified a vast array of variables potentially associated with currency crises, these variables mainly include macroeconomic and financial fundamentals, for instance, money or domestic credit growth, the fiscal deficit, current account deficit, real exchange rate overvaluation, and output growth. Nevertheless, they also contain variables that somehow gauge a country's vulnerability to attacks, such as measures of the adequacy of international reserves relative to possible short-run liabilities of foreign and domestic origin or foreign financing needs. Other possible variables include indicators of market expectations or investors' risk appetite, i. e., interest rate differentials and exposure to contagion from crises in other countries. Trade and financial openness may also affect the likelihood of currency crisis.

The intuition for the association of these variables with currency crises is straightforward. The simple monetary model of exchange rate determination, for example, predicts that money growth in excess of the anchor currency's money growth will cause higher inflation that creates pressure for depreciation of the home currency. If the home country successively resists depreciation for a time, the ultimate fall in the exchange rate may occur as a large discrete movement in the form of a currency crisis. Or a rise in credit growth similarly may imply possible inflationary pressures as well as a rise in the short-term domestic currency liabilities of the banking system. An important indicator of ability to respond to speculative depreciation attacks is the ratio of M2 aggregate to foreign exchange reserves. In the event of a currency crisis, bank depositors may rush to convert their domestic currency assets into foreign currency, therefore this ratio captures the ability of the central bank to meet those demands and stabilize the currency. Relatively large exchange rate overvaluation is expected to be associated with an increased likelihood of a currency crisis because of the negative effects on competitiveness. Adverse performance of the terms of trade because of relatively higher import prices erodes purchasing power and dampens domestic economic activity. Declining real great domestic product growth may signal worsening economic conditions and undermine investor confidence in home country investment opportunities.

There are several ways in which a currency crisis may affect economic activity. On the one hand, a depreciation of the domestic currency that occurs in a successful currency attack,may expand the tradable goods sector and spur growth by correcting an overvalued currency or by making the exchange rate more competitive. On the other hand, a depreciation may be contractionary by increasing the repayment costs of external debts denominated in foreign currencies. In addition, sudden stops or the reversal of capital inflows during a crisis can slow down growth by lowering investment activity, while a rise in the external debt burden from devaluation in the presence of liability dollarization can lower investment activity and growth.

Until the currency crashes of the 1990s, the mainstream view had been that any negative effects from a currency depreciation were ultimately offset by the positive effect of stimulus to net exports, leading to an the overall expansionary effect of a depreciation on output. However, recent literature emphasizes the contractionary effects of depreciations, particularly in developing countries. For instance, Gupta, Mishra, , and Sahay (2003) analized in detail behavior of currency crisis episodes in developing countries during 1970 - 1998, which proved that more than three-fifths of the crises in the sample were contractionary, and that output contraction was more likely greater in large and more developing economies than in small and less developing economies, and crises in countries preceded by large capital inflows were more likely to be associated with contraction during crises. Hutchison and Noy (2006) investigated the output effects of currency and banking crises in emerging markets during 1975-97 and found out that currency crises are very costly, reducing output by about 5 to 8% over a 2 to 4 year period. They also showed that currency crises accompanied by sudden stops have especially severe economic consequences, as the abrupt reversal in foreign credit inflows in conjunction with a realignment of the exchange rate typically cause a sharp drop in domestic investment, domestic production, and employment. An analysis of currency and banking crises by the International Monetary Fund calculating the output losses over time associated with currency crises in emerging markets from the early 1970s to 2002 shows the average decline in output corresponding to currency crises periods relative to trend and indicates that the medium-term output losses following crises are substantial. On average, output falls steadily below its pre-crisis trend until the second or third year after the crisis and does not fully recover to its pre-crisis trend. Thus currency crises can have adverse long-term effects. Nevertheless, countries that are more open to trade are likely to experience less dramatic drops in real growth and much quicker rebounds in the aftermath of a currency crisis.

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3. Meaning and concepts of exchange market pressure

Measuring of exchange market pressure has attracted the attention of many researchers and a great number of theoretical as well as empirical papers have been published. Whereas some empirical papers are focused straight on estimation of exchange market pressure in a variety of regions and countries, other studies use the exchange market pressure measure as an element of a subsequent analysis examining currency crises, monetary policy, foreign exchange intervention, exchange rate regime and other issues.

3.1 Literature review

In the first part of literature review we refer to papers that brought the most important ideas into measuring exchange market pressure. Then we briefly mention an article that employs extreme value theory for currency crises identification and in the last part we list studies analyzing exchange market pressure in four central European countries.

The literature on measuring exchange market pressure usually refers to changes in the exchange rate and foreign exchange interventions in relieving the pressure. The article by Girton and Roper (1977), the best known in the field, uses monetary approach, in the sense that it organizes the analysis around the demands and supplies of national monies. They first used the term *exchange market pressure* to refer to the magnitude of money market disequilibrium that must be removed either through reserve or exchange rate changes. In other words an excess demand or supply for a currency could result in both a change in the price of foreign exchange and a change in the level of foreign exchange reserves of the home country. They derived their measure of exchange market pressure in a monetary model with two large interdependent economies and used it to quantify the volume of central bank foreign exchange intervention necessary to achieve any desired exchange rate target. Their model specification and their assumption that policy authorities do not employ any instrument to influence exchange rate levels ensures that exchange market pressure is the simple sum of the percentage change in the exchange rate and in foreign exchange reserves, thus their exchange market pressure index measures the magnitude of external imbalance. The importance of the concept is that it is equally relevant to all exchange rate systems and to different degrees of exchange rate management, i. e., the model is valid irrespective of exchange rate regime. Moreover, the paper by Girton and Roper (1977) can be considered as a point of departure for many other authors.

Roper and Tumovsky (1980) modified the previous model using a stochastic small open economy IS-LM model to quantify the international excess demand for the domestic currency. They allowed intervention to take the form of changes in domestic interest rates as well as changes in the exchange rate and foreign exchange reserves. They also introduce a policy reaction function that describes foreign exchange or money market intervention as a function of the observed deviation of the exchange rate from its long-run equilibrium level. In this framework, they formulated the optimal stabilization policy in terms of the central bank's optimal response to changes in exchange market pressure. However, this work only focuses on discussion and critical assessment of suggested exchange market pressure model irrespective to the monetary policy. In their model, as it will be shown later on, the excess demand for domestic currency is equal to an unequally weighted linear combination of changes in the exchange rate and in the monetary base.

Later studies concerning on exchange market pressure quantification, namely Eichengreen, Rose, and Wyplosz (1995) and a follow-up paper of the same authors (Eichengreen, Rose, and Wyplosz (1996)), utilized the framework introduced by Girton and Roper (1977) to analyze currency crises by deriving a measure of speculative attacks. The model was slightly modified in order to capture both successful and unsuccessful speculative attacks. As a model independent measure of speculative pressure, they propose a linear combination of the change in the relevant interest rate differential, the percentage change in the bilateral exchange rate, and the percentage change in foreign reserves of the domestic central bank. The weights assigned to the components of this index are chosen to equalize their conditional volatilities. This is obviously an ad hoc approach and the majority of empirical studies shows little success for structural models to forecast foreign exchange in short and intermediate horizons. According to Weymark (1998), the relative volatilities of observed changes in the exchange rate, in the central bank's foreign reserves, and in the interest rate differential necessarily depend on the structure of the economy as well as on the intervention activities of the central bank. This means that volatility smoothing weights cannot be expected to ensure that the components of the index of speculative pressure are commensurate. Consequently, the index constructed by Eichengreen, Rose, and Wyplosz (1996) thus cannot be interpreted as a cardinal or even ordinal measure of speculative pressure in the context of any model. Weymark (1998) also denies that the poor track record of structural models in forecasting exchange rate changes precludes their use in the construction of operational indices. She argues that a poor understanding of market participants' expectation formation process and an inability to model this process correctly is probably the primary source of these forecasting difficulties. However the methodology introduced by Eichengreen, Rose, and Wyplosz (1996) has received extensive attention from other researchers and on its basis a variety of different versions of indices has been devised to identify currency crisis episodes, for instance, Sachs, Tornell, and Velasco (1996) or Kaminsky, Lizondo, and Reinhart

(1998). An approach stemming from Eichengreen, Rose, and Wyplosz (1996) was also followed by Pentecost, van Hooydonk, and van Poeck (2001). However, they determined the weights using principle components analysis.

Weymark (1998) used the formulas derived by Girton and Roper (1977) and Roper and Tumovsky (1980) as a point of departure for developing a general approach to measure exchange market pressure. Moreover, the author formulates definition of exchange market pressure which is accepted as a general consent by all economists (see Definition 3). Her principal idea is to consider the calculation of exchange market pressure as a measurement experiment at time t in which the actual magnitude of external imbalance is calculated, given the policy in place during that period. This means that all relevant information about expectations and stochastic disturbances is captured in the changes in the observed variables that relieve this external imbalance. Moreover, the author adjusts the model with respect to a proportion of foreign exchange intervention that is sterilized by a change in domestic credit and thus she implements intervention policy. In the article, she introduced a model that generates a relationship between exchange market pressure and observed changes in both the exchange rate and the components of the monetary base. The author argues that imbalance between the demand and supply of a given currency in international markets occurs when the total vale of domestic goods and assets demanded by foreigns do not equal to total value of foreign goods and assets required by domestic residence. In a freely floating exchange rate regime, therefore, the observed change in the exchange rate provides a measure of the imbalance, and conversely, in a fixed exchange rate regime the imbalance can be detected by changes in foreign exchange reserves. In an intermediate exchange rate regime (pegged systems with fluctuation bands) both these channels should be accounted together with possible accommodation of domestic credit changes.

The idea of using extreme value theory for identification of currency crises stems from the article by Haile and Pozo (2006). Their paper, besides employing extreme value theory, is distinguishable from others in using two separate designations for the exchange regime in place. The first is the self-reported or announced exchange rate system. The second classification scheme is based on the relative movements of international reserves and exchange rates. They exploited the model of exchange market pressure suggested by Eichengreen, Rose, and Wyplosz (1996), i.e., the index takes into account changes in the exchange rate, difference in interest rates, as well as difference in reserve losses. While large values for the index are indicative of currency crisis periods, they arose the question how to define "large". Typically, large has been defined as values for the index that exceed its mean by a specific multiple (usually 1.5 or 2) standard deviations. Thus the designation of "largeness" is arbitrary. They deviated from the standard approach and used extreme value analysis to distinguish small, noncrisis values in the index, from large, crisis values in the index. Their main argument

for using extreme value theory is that the tail of the distribution of exchange market pressure index constitutes its outliers, which are the results of successful and unsuccessful pressures against the currency, i.e. currency crisis periods. A good indicator for the mass in the tails is the tail index. Extreme value theory develops a method for estimating the tail index for distributions having sparse observations on their tails based on these outliers.

The first study estimating exchange market pressure in the Czech Republic and Poland was elaborated by Tanner (2002). Using the model by Girton and Roper (1977), he examined the relationship between exchange market pressure and monetary policy (mainly relationship between exchange market pressure and domestic money supply). Van Poeck, Vanneste, and Veiner (2007) used exchange market pressure as an indicator of currency crisis and addressed the question whether currency crises in the euro candidate countries have been more frequent in fixed, intermediate or flexible exchange rate arrangements. The authors found that exchange market pressure was marginally smaller in countries and periods characterized by an intermediate exchange rate regime as compared to those with a floating arrangement. Regarding four central European countries (Czech Republic, Hungary, Poland and Slovakia), the most critical quarters occurred in Hungary during the fixed peg regime and in Poland when a crawling peg was being applied. Very similar conclusions were drawn earlier in the study of Stavárek (2008) where exchange market pressure in the Czech Republic, Hungary, Poland and Slovenia between 1993 and 2004 are estimated. The study applied the measure proposed in Eichengreen, Rose, and Wyplosz (1995) and the results obtained suggest that the Czech Republic and Slovenia went through considerably less volatile development of exchange market pressure than Hungary and Poland. Finally, the paper by Stavárek (2010) estimates the exchange market pressure in four central European countries (Czech Republic, Hungary, Poland, Slovakia) over the period 1995 - 2008. He is the very first author applying concurrently model dependent as well as model independent approaches to exchange market pressure estimation to these countries. He found out that the approaches lead to inconsistent findings, in particular they often differ in identification of the principal development trends, as well as the magnitude and direction of the pressure.

3.2   Measuring exchange market pressure

Since currency crisis occurs when there is an abnormally large international excess demand for a currency, a natural way to obtain a summary statistic that can be used to characterize exchange market conditions is to develop an analytically sound measure of the total international excess demand for a currency. For many decades, economists have focused on the problem of measuring exchange market pressure by a mechanism that would incorporate these channels into a single measure of international financial conditions faced by the country at a specific

time. As a result they came up with so called *exchange market pressure index*, a single number which expresses the magnitude of the shocks and the depth of the consequent currency crises.

According to the monetary approach to exchange rate determination, imbalance between the demand and supply of domestic currency in the international foreign exchange market occurs when the total value of foreign assets and goods demanded by domestic residents is not equal to the total value of domestic assets and goods demanded by foreign residents at the prevailing exchange rate level. To balance the market, the price or quantity of domestic assets in circulation, i.e., the exchange rate or the money supply, must change. Given the money multiplier, the change in money supply depends on the money and foreign exchange market interventions of the domestic central bank. Thus a country adjusts to international shocks through four potential paths: change in the exchange rate, intervention by the central bank, raising or lowering the interest rate, and modifying capital controls both in an attempt at influencing the exchange rate. This offers a natural way of characterizing exchange market conditions: the total international excess demand or supply of the domestic currency can be measured quantitatively by forming a summary statistic from observed changes in exchange rate, domestic interest rates and foreign exchange reserves of the domestic central bank. This magnitude of money market disequilibrium can also be called exchange market pressure.

The following statement, proposed by Weymark (1998), is broadly accepted as a general model independent definition of exchange market pressure:

Definition 3. *Exchange market pressure measures the total excess demand for a currency in international markets as the exchange rate change that would have been required to remove this excess demand in the absence of exchange market intervention, given the expectations generated by the exchange rate policy actually implemented.*

In other words,the amount of exchange market pressure is the size of the exchange rate change that would have occurred if the central bank had unexpectedly refrained from intervening in the money or foreign exchange market. Therefore, because expectations associated with a free float will differ from those held under the policy actually implemented, exchange market pressure is not generally equivalent to the exchange rate change that would have occurred under a free floating exchange rate system. Rather, exchange market pressure is best associated with the magnitude of external imbalance.

According to Weymark (1998), the above model independent definition of exchange market pressure has two important features. First, because it defines

exchange market pressure as the excess demand for domestic currency in international markets, it can be used to obtain model consistent measures with models that do not emphasize the monetary approach to exchange rate determination, as well as with those that do. The definition is applicable to any model in which the demand for domestic currency responds contemporaneously to exchange rate changes. Second, because it measures the excess demand for domestic currency associated with the expectations held under the exchange rate and monetary policy actually implemented, it measures the actual external imbalance rather than the external imbalance that would have occurred under a pure float. If the domestic currency were allowed to float freely, exchange market pressure could, of course, be observed directly. If the exchange rate were held fixed, changes in foreign exchange reserves and domestic credit would reflect the size of external imbalance. With intermediate exchange rate systems, the magnitude of exchange market pressure has to be calculated from observed changes in the exchange rate, domestic credit and foreign exchange reserves.[1]

In the following text we introduce the most relevant approaches to construction of the index together with a critical discussion on their practical application. In the first section we present so called model dependent approach which utilizes monetary theory of exchange rate determination. In the section we present models of exchange market pressure indices that are constructed independently of any particular model. As a result we state the final model that is used in our computational experiment and we describe the estimation procedure.

3.2.1 Model dependent approach

The first model introduced by Girton and Roper (1977) implicitly defines exchange market pressure index as the magnitude of external imbalance. They assume that excess demand expressed by the index is a result of a change in the price of foreign exchange and a change in the level of foreign exchange reserves of the home country. Thus the index is given as:

$$EMP_{j,t}^{GR} = \Delta e_{j,t} - \Delta r_{j,t}, \tag{3.1}$$

where $EMP_{j,t}^{GR}$ denotes the exchange market pressure for country j at time t. $e_{j,t}$ express the nominal exchange rate between currency of country j and currency of reference country, i.e., the number of units of the currency of country j that can purchase a unit of a reference foreign currency. $r_{j,t}$ denotes the ratio of international reserves of country j in domestic currency to money supply. Symbol

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[1] The monetary units in which changes in reserves and domestic credit are measured are not commensurate with the units in which exchange rate changes are measured. To yield a commensurable composite index of external imbalance,changes in foreign exchange reserves and domestic credit have to be converted into exchange-rate-equivalent units and combined with changes in the exchange rate.

$\Delta e_{j,t} = e_{j,t} - e_{j,t-1}$, thus it expresses change in a nominal exchange rate between two sequent observations (similar formula for $\Delta r_{j,t}$).

Many other authors pointed out that the model suggested by Girton and Roper (1977) concerns inconsistency in units of explanatory variable, i.e. dimensional analysis suggest that the units of all included components have to be consistent. Thus, the index simply sums up change in exchange rate and change in reserves. However it would be more relevant if the index considers relative (percentage) changes in these components.

The most cited source to determination of exchange market pressure in mentioned numerous articles is a study elaborated by Weymark (1998). As mentioned in the previous part the idea of the methodology is to generate a model-dependent summary statistic based on a model-independent definition of exchange market pressure. An exchange market pressure formula consistent with the idea is given as

$$EMP_{j,t}^{W} = \frac{\Delta e_{j,t}}{e_{j,t-1}} + \eta_j \left((1 - \lambda_j) \frac{\Delta r_{j,t}}{r_{j,t-1}} - \Delta i_{j,t} \right), \tag{3.2}$$

where $EMP_{j,t}^{W}$ denotes the exchange market pressure for country j at time t. Symbol $\Delta e_{j,t}$ denotes the percentage change in the domestic currency cost of one unit of foreign currency, $\Delta r_{j,t}$ change in official foreign exchange reserves expressed as a percentage of the inherited monetary base and $\Delta i_{j,t}$ the autonomous percentage change in domestic interest rates. It is natural to assume that the central bank tries to dampen fluctuations in the exchange rate, i.e., purchases foreign bonds when there is excess demand for domestic currency and the exchange market pressure is negative, and sells foreign bonds when there is excess supply of domestic currency and the exchange market pressure is positive. This policy implies that the convention coefficient η_j should be negative. Thus, parameter η_j, defined as

$$\eta_j = -\frac{\partial \Delta e_{j,t}}{\partial \Delta r_{j,t}}, \tag{3.3}$$

expresses the negative of the elasticity of the exchange rate with respect to foreign exchange reserves. The elasticity η_j is however not directly observable and must be estimated from data, for instance, utilized a structural model in order to estimate this parameter (the exact estimation procedure is summarized beneath). Finally, parameter λ_j is the proportion of foreign exchange intervention that is sterilized by a change in domestic credit due to changes in interest rates induced by suitable monetary policy of the central bank.

Let us recall that if the domestic credit channel is included in the exchange pressure formula, the central bank changes autonomous domestic lending only to affect the exchange rate, i.e. monetary policy is dependent on conditions in the foreign exchange market as under a fixed exchange rate regime. If the channel is excluded from formula, autonomous changes in domestic lending are exogenous

to the central bank's foreign exchange policy, i.e. monetary policy is independent from conditions in the foreign exchange market as under a dirty float exchange rate regime. If the change in domestic credit, $\Delta i_{j,t}$, and the change in foreign exchange reserves, $\Delta r_{j,t}/r_{j,t-1}$, are of opposite sign, central bank uses money market intervention to sterilize the effect of a foreign exchange intervention on domestic money supply. If $\Delta i_{j,t}$ and $\Delta r_{j,t}/r_{j,t-1}$ are of the same sign, the central bank uses money market intervention to reinforce the effect of a foreign exchange intervention on the exchange rate.

Now assume that the central bank follows the dirty float exchange rate regime with partly sterilized foreign exchange intervention. It is also assumed that the central bank's domestic monetary policy is completely independent of the demand and supply conditions for the domestic currency in the international foreign exchange market. This means that autonomous money market interventions, i. e., changes in domestic credit not due to sterilization operations, are not assumed to be an instrument of exchange rate policy. In other words, autonomous money market interventions are executed solely to affect banking sector liquidity, not to affect the exchange rate or remove exchange market pressure. Hence, autonomous changes in domestic credit are exogenous, and the adjusted formula for calculating exchange market pressure is

$$EMP_{j,t}^W = \frac{\Delta e_{j,t}}{e_{j,t-1}} + \eta_j \left(1 - \lambda_j\right) \frac{\Delta r_{j,t}}{r_{j,t-1}}, \tag{3.4}$$

where the meaning of the variables remains consistent.

Remark 4. In many sources the model constructed by Weymark (1998) is refered abstracting parameter λ_j, which can be interpreted as there are no accommodating domestic credit changes. For this case the suggested formula has the form

$$EMP_{j,t}^W = \frac{\Delta e_{j,t}}{e_{j,t-1}} + \eta_j \frac{\Delta r_{j,t}}{r_{j,t-1}},$$

where the explanatory variables are again the percentage change in the domestic currency cost of one unit of foreign currency and the change in official foreign exchange reserves expressed as a percentage of the inherited monetary base. We emphasize that when the policy authority employs domestic credit changes via unsterilized or sterilized intervention, the formula above must be amended as describe in the previous text.

As mentioned above, the monetary theory is the sound basis of the model dependent approach of constructing exchange market pressure measures that includes model suggested by Weymark (1998) as well as that one by Girton and Roper (1977). Since the monetarist and rational expectations revolution in macroeconomics in the early 1970s, the exchange rate has been more and more viewed

as an asset price which depends on the current and expected future values of relative supply of domestic and foreign financial assets, i.e., monies and bonds, and the relative domestic and foreign income. Monetary models[2] seek to explain how changes in the domestic and foreign supply and demand for money, both directly and indirectly, influence the exchange rate (in contrast to the Keynesian Mundell-Fleming model in which prices are assumed to be fixed in the short run, the monetary model of exchange rate determination is more classical in spirit that prices are assumed to be flexible also in the short run). Whereas Girton and Roper (1977) constructed their exchange market pressure measure in a monetary model with two large interdependent economies, practical estimation of the index by Weymark (1998) was carried on in small open economy environment. Since in this thesis we focus on the central European countries, that can be considered as small open economies, we state the system of equations as used in Weymark (1998)

$$\Delta m_{j,t}^d = \beta_{j,0} + \Delta p_{j,t} + \beta_{j,1} \ \Delta c_{j,t} - \beta_{j,2} \ \Delta i_{j,t}, \tag{3.5}$$

$$\Delta p_{j,t} = \alpha_{j,0} + \alpha_{j,1} \ \Delta p_t^* + \alpha_{j,2} \ \Delta e_{j,t}, \tag{3.6}$$

$$\Delta i_{j,t} = \Delta i_t^* + \mathbb{E}_t \left(\Delta e_{j,t+1} \right) - \Delta e_{j,t}, \tag{3.7}$$

$$\Delta m_t^s = \Delta d_{j,t}^a + (1 - \lambda_j) \ \Delta r_{j,t}, \tag{3.8}$$

$$\Delta r_{j,t} = -\kappa_{j,t} \ \Delta e_{j,t}, \tag{3.9}$$

$$\Delta d_{j,t}^a = \gamma_{j,0} + \Delta y_{j,t}^{\mathrm{trend}} + (1 - \gamma_{j,1}) \ \Delta p_{j,t} - \gamma_{j,2} \ y_{j,t}^{gap}, \tag{3.10}$$

$$\Delta m_{j,t}^d = \Delta m_{j,t}^s, \tag{3.11}$$

The model additionally assmues that the money multiplier is invariant. The explanatory variables have the following meanin. $p_{j,t}$ denotes domestic price level, p_t^* is price level of a reference country, $e_{j,t}$, as before, denotes exchange rate in direct quotation, $m_{j,t}$ is nominal money stock (intuitively, the subscript d corresponds to the demand and s represents the supply), $c_{j,t}$ is real domestic income, $i_{j,t}$ represents nominal domestic interest rate and i_t^* nominal interest rate of a reference country. Symbol $\mathbb{E}_t(\Delta e_{j,t+1})$ denotes expected exchange rate change and λ_j is proportion of sterilized intervention. Further, $d_{j,t}^a$ is autonomous domestic lending by the central bank and $r_{j,t}$ is the stock of foreign exchange reserves, both divided by the one period lagged value of the money base. $y_{j,t}^{\mathrm{trend}}$ is the long-run trend component of real domestic output $y_{j,t}$ and $y_{j,t}^{\mathrm{gap}}$ is the difference between $y_{j,t}$ and $y_{j,t}^{\mathrm{trend}}$. The sign Δ naturally denotes change in the respective variable. Parameters $\alpha_{j,k}, \beta_{j,k}$ and $\gamma_{j,k}$ for $k = 0, 1, 2$ are estimated regression parameters. Note that the regression parameters can be considered as elasticities of relevant variables, for instance, parameter $\alpha_{j,2}$ can be interpreted as the elasticity of the domestic price level with respect to the exchange rate.

Equation 3.5 suggests that change in money demand can be estimated by a regres-

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[2] The papers on the original version of the monetary approach are to be found in Frenkel and Johnson (1976)

sion model with three independent variables, change in domestic inflation, change in real domestic income and change in domestic interest rate. Equation 3.6 defines the purchasing power parity condition attributing the primary role in domestic inflation determination to exchange rate changes and foreign inflation. As in the previous case, we can employ a simple regression model. Equation 3.7 describes uncovered interest rate parity. Equation 3.8 suggests that change in the money supply is positively influenced by autonomous changes in domestic lending and nonsterilized changes in the stock of foreign reserves. Equation 3.9 states that changes in foreign exchange reserves are a function of the exchange rate and a time-varying response coefficient $\kappa_{j,t}$. Equation 3.10 describes the evolution of the central bank's domestic lending. Whereas change in domestic inflation and change in trend of real output are positive determinants, the gap between real output and its trend has a negative impact on domestic lending activity. Equation 3.11 defines a money market clearing condition, i.e., change in money demand has to be equal change in to money supply.

In order to derive the expression for conversion factor, Formula 3.3, we can proceed as follows. Firstly we substitute Equations 3.6 and 3.7 into Equation 3.5 and Equation 3.10 into Equation 3.8. Thus we get

$$\Delta m_{j,t}^d = \beta_{j,0} + \alpha_{j,0} + \alpha_{j,1} \, \Delta p_t^* + \beta_{j,1} \, \Delta c_{j,t} - \beta_{j,2} \, \Delta i_t^* + \beta_{j,2} \, \mathbb{E}_t \left(\Delta e_{j,t+1} \right) +$$
$$+ \left(\alpha_{j,2} - \beta_{j,2} \right) \Delta e_{j,t},$$
$$\Delta m_t^s = \gamma_{j,0} + \Delta y_{j,t}^{\text{trend}} + \left(1 - \gamma_{j,1} \right) \Delta p_{j,t} - \gamma_{j,2} \, y_{j,t}^{gap} + \left(1 - \lambda_j \right) \Delta r_{j,t}.$$

In the next step, using the money market clearing condition in Equation 3.11 to set the previous two equations equal to one another, we obtain the following relation

$$\Delta \, e_{j,t} = \frac{X_{j,t} + \beta_{j,2} \, \mathbb{E}_t \left(\Delta e_{j,t+1} \right) + \left(1 - \lambda_j \right) \Delta r_{j,t}}{\gamma_{j,1} \alpha_{j,2} + \beta_{j,2}}, \tag{3.12}$$

where

$$X_{j,t} = \gamma_{j,0} - \gamma_{j,1} \alpha_{j,0} - \beta_{j,0} + \Delta y_{j,t}^{\text{trend}} - \gamma_{j,1} \alpha_{j,1} \, \Delta p_t^* - \gamma_{j,2} \, y_{j,t}^{gap} - \beta_{j,1} \, \Delta c_{j,t} + \beta_{j,2} \, \Delta i_t^*$$

and thus the elasticity defined in Formula 3.3 can be calculated as

$$\eta_j = -\frac{1 - \lambda_j}{\gamma_{j,1} \alpha_{j,2} + \beta_{j,2}}. \tag{3.13}$$

by differentiating Equation 3.12 with respect to $\Delta r_{j,t}$.

3.2.2   Model independent approach

Many researchers have criticized the most undesirable aspect of the exchange market pressure measure, dependency on a particular model, and proposed some alternative approaches called model independent approach. Such a model was originally constructed by Eichengreen, Rose, and Wyplosz (1995) and was inspired by

previous model by Girton and Roper (1977). The model was modified by adding an extra channel that influenced an excess demand in foreign exchange, namely that was a change in difference between domestic and foreign interest rates. The inclusion of the channel in the exchange market pressure formula can be interpreted in the following way. The central bank changes autonomous domestic lending only to affect the exchange rate, i.e. monetary policy is dependent on conditions in the foreign exchange market as under a fixed exchange rate regime. If the channel is excluded from formula, autonomous changes in domestic lending are exogenous to the central bank's foreign exchange policy, i.e. monetary policy is independent from conditions in the foreign exchange market as under a dirty float exchange rate regime.

The index constructed by Eichengreen, Rose, and Wyplosz (1995) quantifies the speculative pressure via weighted average of exchange rate changes, international reserves changes, and interest rate changes. Contrary to Weymark's approach, the weights are set in such a manner to equalize the volatility of all three components with no need to estimate any model. All of these variables are measured relative to a reference foreign currency. A logical choice for the reference country would be a country with a fairly strong and stable currency. Eichengreen, Rose, and Wyplosz (1995) formulated the index as follows:

$$EMP_{j,t}^{ERW} = \frac{1}{\sigma_j^e} \frac{\Delta e_{j,t}}{e_{j,t-1}} - \frac{1}{\sigma_j^r} \left(\frac{\Delta r_{j,t}}{r_{j,t-1}} - \frac{\Delta r_t^*}{r_{t-1}^*} \right) + \frac{1}{\sigma_j^i} \Delta \left(i_{j,t} - i_t^* \right), \qquad (3.14)$$

where $EMP_{j,t}^{ERW}$ denotes the exchange market pressure for country j at time t. $e_{j,t}$ again denotes the nominal exchange rate between currency of country j and currency of reference country, $r_{j,t}$ indicates the ratio of international reserves of country j in domestic currency to its narrow money (M1) at time t, note that Girton and Roper (1977) used relation to money supply M0. $i_{j,t}$ is the money market interest or similar rates for country j related to time t. Symbols $\Delta e_{j,t}$, $\Delta r_{j,t}$, Δr_t^* and $\Delta (i_{j,t} - i_t^*)$ have the same meaning as in the previous model. σ_j^e, σ_j^r and σ_j^i are the weights related to a particular country computed based on the volatility of each component. All factors with an asterisk represent similar variables of the reference country.

Weighting the model variables is a crucial issue. The easiest option is to assign to each component the weight equal to one, nevertheless the volatilities of exchange rates, international reserves, and interest rates are very different, and in that case the index is heavily dominated by fluctuation of the international reserves which have the highest volatility in comparison with the other components. The methodology of weighting should reflects different manners in the volatilities in such a way that the they are equilized and EMP index is not dominated by only one of the components. Therefore it seems to be reasonable to adopt the reciprocal value of the standard deviation as the weight for each variable. Although this approach adjusts each component's weight with its own volatility, and thus

it does not exactly equalize the share of the components, in many of application it provides satisfactory results. In further text we state several possible adjustments proposed by different authors in order to improve explanatory properties of EMP index by reformulating the weighting vector. It is necessary to note that the technique of weighting may not be accurate in dating periods of crisis, if the volatilities of the components are mostly caused by the policy reaction function of the central banks rather than being market determined. Some of the approaches use time-invariant weights, but since the conditional variances of the three components of EMP is more likely to be variable, the weights can be modified as time varying. The most commonly applied methodology for time-varying conditional standard deviations is than ARCH or GARCH models.

Eichengreen, Rose, and Wyplosz (1995) define crises as periods when the index reaches large positive value. The periods of currency crises are traced using a binary (dummy) variable $I_{j,t}$, i.e. $I_{j,t} = 1$ when the crises at time t is detected, and $I_{j,t} = 0$ oterwise. They suggested the following mathematical formula:

$$
\begin{aligned}
I_{j,t} &= 1 \qquad \text{if } EMP_{j,t}^{ERW} > \mu_{EMP} + \delta\sigma_{EMP}, \\
&= 0 \qquad \text{otherwise,}
\end{aligned} \tag{3.15}
$$

where μ_{EMP} and σ_{EMP} represent the mean and standard deviation of the entire sample of $EMP_{j,t}^{ERW}$, and δ is a threshold to be chosen (in their study they set the value as 1.5).

The arbitrary choice of the crisis identification threshold is a problematic issue. Obviously, different choices result in different crisis episodes. As Karimi and Voia (2011) pointed out, use of the mean and standard deviation approach to determine extreme observations is based on normally distributed series of EMP values. However, it is well known that speculative price series turn out to be more compatible with heavy-tailed distributions, for instance log-normal, log-gamma, Cauchy, Student t-distribution and many others. Therefore, the arbitrary choice of thresholds results in picking up extremely large values. Therefore, we apply an alternative methodology to capture the dispersion of the series and label their extreme values in a rigorous manner in the spirit of extreme value theory.

Sachs, Tornell, and Velasco (1996) and Kaminsky, Lizondo, and Reinhart (1998) slightly modified the EMP index formulated by Eichengreen, Rose, and Wyplosz (1996) by dropping the interest rate component, arguing lack of availability or reliability of data for countries and time periods used in their sample research. They proposed the following modification of EMP index:

$$
EMP_{j,t}^{STV} = \left(\frac{\frac{1}{\sigma_j^e}}{K_j} \right) \frac{\Delta e_{j,t}}{e_{j,t-1}} - \left(\frac{\frac{1}{\sigma_j^r}}{K_j} \right) \frac{\Delta r_{j,t}}{r_{j,t-1}} + \left(\frac{\frac{1}{\sigma_j^i}}{K_j} \right) \Delta i_{j,t}, \tag{3.16}
$$

where

$$
K_j = \frac{1}{\sigma_j^e} + \frac{1}{\sigma_j^r} + \frac{1}{\sigma_j^i},
$$

22

and

$$EMP_{j,t}^{KLR} = \frac{\Delta e_{j,t}}{e_{j,t-1}} - \frac{\sigma_j^e}{\sigma_j^r}\frac{\Delta r_{j,t}}{r_{j,t-1}} + \frac{\sigma_j^e}{\sigma_j^i}\Delta i_{j,t}. \qquad (3.17)$$

$EMP_{j,t}^{STV}$ and $EMP_{j,t}^{KLR}$ denote the indices for country j at time t suggested by Sachs, Tornell, and Velasco (1996) and Kaminsky, Lizondo, and Reinhart (1998) respectively. The rest of the notations is the same as for $EMP_{j,t}^{ERW}$. Note that the measure by Sachs, Tornell, and Velasco (1996) consists of the same elements as that one by Eichengreen, Rose, and Wyplosz (1995), but each weight in the index is calculated with respect to standard deviations of all components included instead of using only standard deviation of the respective component. In the case of Kaminsky, Lizondo, and Reinhart (1998), the weights on the reserves and interest rate terms are the ratio of the standard error of the percentage change of the exchange rate over the standard error of the percentage change of reserves and the interest rate differential, respectively. Furthermore, in both articles the interest rate differential is substituted by a relevant interest rate in the analyzed country.

The idea of exchange market pressure quantification is based on the central bank intervention, but many existing exchange market pressure estimators utilize the change in reserves. One could argue that the change in reserves is a poor measure of intervention, since it is distorted by valuation effects and related interest income. Furthermore, not all changes in international reserves are due to intervention in exchange markets. This explanatory variable can be replaced by an estimate of intervention, for instance the approach suggested in a recent work of Dominguez, Hashimoto, and Ito (2011) can be adopted. Proposed estimate of intervention comprises measurement error that can be substantial, and thus the substitution can obscure the resulting index. They argue that the estimates of intervention still performs better than the pure change in reserves that has been in the majority of models. Estimation of the central bank intervention presented in their work is drawn on the assumption that each country has a portfolio composition of reserves which is the same as the average reported in the IMF COFER database. Data for individual countries are strictly confidential, thus they have to be used in aggregated form for a specific group of countries (advanced countries and emerging and developing countries). This approach enables estimation of valuation changes and interest income, through which the observed change in reserves can be transformed into an estimate of intervention. Subsequently, in the spirit of Dominguez, Hashimoto, and Ito (2011), the following methodology can be used

$$\Delta r_{j,t}^* = r_{j,t} - r_{j,t-1} - \phi_{j,t-1,t} - \delta_{j,t-1,t},$$
$$\phi_{j,t-1,t} = r_{j,t-1}\ i_{j,t-1},$$
$$\delta_{j,t-1,t} = r_{j,t-1}\frac{\Delta e_{j,t}}{e_{j,t-1}},$$

where $\Delta r_{j,t}^*$ denotes the central bank intervention, $i_{j,t-1}$ is the interest rate (for instance 10-year government bond yield), symbol $\phi_{j,t-1,t}$ denotes interest income related to time interval $(t-1,t)$ and symbol $\delta_{j,t-1,t}$ expresses valuation effect.

Beside approximation using the `IMF COFER` database, many different approaches have been employed. Here we additionally state one of the most simply. Since it is highly probable that the major part of the central bank reserves is concentrated in one currency of a particular reference country, one could assume that each country concentrates all its reserves into one currency of a reference country. This country is chosen to be the same as the reference country considered in nominal exchange rate. We emphasize that the exact diversification in reserves is unknown and only an approximation can be adopted, thus the distortion in estimation of intervention is unavoidable and can be substantial.

3.2.3 Comparison of alternative approaches

In this section we mainly refer to the papers by Stavárek (2008) and Stavárek (2010) who implemented model dependent approach as well as model independent approach and focused on their comparison. Firstly, let us discuss model dependent estimation procedure and make a conclusion. The authors employed model suggested by Weymark (1998) presented in Subsection 3.2.1. They assumed that the central banks of considered countries follow the exchange rate regime with partly sterilized foreign exchange intervention. Moreover, for each central bank they assumed that its domestic monetary policy is independent of the demand and supply conditions for the domestic currency in the international foreign exchange market, as explained before, this means that autonomous money market interventions are executed solely to affect banking sector liquidity, not to affect the exchange rate or remove exchange market pressure. Therefore, autonomous changes in domestic credit are exogenous, and the expression for calculating exchange market pressure is given by Formula 3.4.

Obviously, the exchange market pressure estimation must be preceded by the calculation of the conversion factor according to Formula 3.13. However, this step requires previous calculation of the sterilization coefficient which can be obtained from Equation 3.8. Solving the equation involves estimating all regression parameters considered in the monetary model presented at the end of Subsection 3.2.1. In practice, the regression parameters are obtained by estimating the following system of equations that can be easily obtained from the original system of equations

$$\Delta m_{j,t}^d - \Delta p_{j,t} = \beta_{j,0} + \beta_{j,1}\ \Delta c_{j,t} - \beta_{j,2}\ \Delta i_{j,t} + \epsilon_{j,t,1},$$
$$\Delta p_{j,t} = \alpha_{j,0} + \alpha_{j,1}\ \Delta p_t^* + \alpha_{j,2}\ \Delta e_{j,t} + \epsilon_{j,t,2},$$

$$\Delta m_{j,t}^s - \Delta r_{j,t} - \Delta y_{j,t}^{\text{trend}} - \Delta p_{j,t} = \gamma_{j,0} + \gamma_{j,1}\,\Delta p_{j,t} + \gamma_{j,2}\,y_{j,t}^{gap} + \lambda_j\,\Delta r_{j,t} + \epsilon_{j,t,3},$$

where $\epsilon_{j,t,1}$, $\epsilon_{j,t,2}$ and $\epsilon_{j,t,3}$ are independent white noises. In the third equations (the money supply equation) we assume that change in money supply equals to change in money base, i.e., $\Delta B_{j,t}/B_{j,t-1}$, on the condition that the money multiplier is invariant. There are two types of variables in the considered model, endogenous and exogenous. The first set of variables includes $\Delta m_{j,t}$, $\Delta p_{j,t}$, $\Delta e_{j,t}$, $\Delta m_{j,t}^s = \Delta i_{j,t}$, $\Delta B_{j,t}/B_{j,t-1}$ and $\Delta r_{j,t}$. Although $\Delta e_{j,t}$ does not appear on the left-hand side of any of the equations, it is the endogenous variable since the exchange rate is clearly the variable determined by the model. The exogenous variables are $\Delta c_{j,t}$, Δp_t^*, Δi_t^*, $\Delta y_{j,t}^{\text{trend}}$ and $\Delta y_{j,t}^{\text{gap}}$.

The model has to be estimated using the two-stage least square regression technique. As explained by Stavárek (2010), the main reason is that the endogenous variables appear on both sides of equations of the model described in Subsection 3.2.1 (Equations 3.5 - 3.11). Since some of the endogenous variables occur on the right-hand side, they are very likely to correlate with the stochastic process representing disturbance term and using the ordinary least square method would lead to biased estimates. The two-stage least square regression model used requires the incorporation of instruments (variables uncorrelated with the disturbance term) into the estimation. In order to find appropriate instruments the authors run the first stage regression on endogenous variables, where regressors themselves were set as all feasible instruments. For more detailed description of applied technique, we refer to Stavárek (2010).

In order to calculate desired sequence of exchange market pressure, one needs to estimate the proportion of foreign exchange intervention λ_j, i.e., the sterilization coefficient, and parameters $\alpha_{j,2}$, $\beta_{j,2}$ and $\gamma_{j,1}$, which determine the conversion factor η_j. According to the model specification parameter $\alpha_{j,2}$ should be positive and parameters $\beta_{j,2}$ and $\gamma_{j,1}$ should be negative. Since λ_j is a fraction, its absolute value should fall to interval $[0,1]$. According to Stavárek (2008) or Stavárek (2010), estimates resulting from the money supply equation are somewhat poor. The first study, dealing with estimating the exchange market pressure in four central European countries between 1993 and 2006, showed that the estimate of parameter $\gamma_{j,1}$ does not have to satisfy the positivity condition and the estimate of the sterilization coefficient can exceed the upper margin of the potential interval. The second study of the same author, focusing on estimating the exchange market pressure in the same countries between 1995 and 2008, led to similarly inconsistent results. Moreover, the estimates of parameters necessary for the following computation are very often statistically insignificant. Further, we can observe that estimates of the sterilization coefficient were significantly different from minus unity. However, the results of Wald test of the null hypothesis that the sterilization coefficient equals to minus unity, suggest that the null hypothesis cannot be rejected in the majority of the cases. All these conclusions indicate substantial drawbacks of the model dependent approach.

The second estimation procedure based on the model independent approach specified in Subsection 3.2.2 does not require any derivation of a structural model and therefore calculation of exchange market pressure is considerably simpler. However, as Eichengreen, Rose, and Wyplosz (1995) emphasized that a crucial issue of model independent approach is weighting the model variables. Stavárek (2008) and Stavárek (2010) in both his studies applied model constructed by Eichengreen, Rose, and Wyplosz (1995). He finds out that the exchange market pressure values obtained from the model independent approach are substantially different from those of model dependent ones, they differ in magnitude as well as basic development tendencies. The diametrical results indicate a lack of consistency between the empirical methods applied which can be proved by computing correlation coefficients. Both studies show that the correlation coefficients are low suggesting no linear relationship between the exchange market pressure indices. Insufficient degree of consistency is also reflected in ability of the approaches to identify the currency crisis. Since there are fundamental differences in results obtained from the alternative estimation approaches one should always be cautious when interpreting the exchange market pressure development.

Although there exists a rich literature focusing on comparison of model dependent and model independent approaches, there is no strong evidence that one of the methods preforms better than the other. Taking into account difficulties concerning estimation of structural model dependent approach, we adopt a very simple model independent approach inspired by Kaminsky, Lizondo, and Reinhart (1998) in our computational experiment. We assume that domestic monetary policies of considered countries are independent of the demand and supply conditions for the domestic currency in the international foreign exchange market, and thus autonomous changes in domestic credit are exogenous. Using the same weights as Kaminsky, Lizondo, and Reinhart (1998) we arrive to the following formula for the exchange market pressure index

$$EMP_{j,t} = \frac{\Delta e_{j,t}}{e_{j,t-1}} - \frac{\sigma_j^e}{\sigma_j^r} \frac{\Delta r_{j,t}}{r_{j,t-1}}, \tag{3.18}$$

where the explanatory variables are again the percentage change in the domestic currency cost of one unit of foreign currency, the change in official foreign exchange reserves and σ_j^e and σ_j^r are standard deviations of samples consisting of observation of $\Delta e_{j,t}/e_{j,t-1}$, or $\Delta r_{j,t}/r_{j,t-1}$ respectively. For simplicity we assume that these parameters are time-invariant for each country.

4. Extreme value theory

The dispersion of the EMP index determines periods of successful and unsuccessful speculative attacks. As stated above, well behaved normality does not necessarily hold due to fat tails and skewness in the series. Alternatively, applying extreme value theory enables to exploit information contained in the tails of the series and thus identifies crisis dates with the help of more rigorous statistical methods. Extreme value theory provides a framework to study the behavior of the tails of a distribution. It enables us to apply extreme observations to measure the density in tails and build statistical models for rare phenomena like stock-market crashes or speculative attacks.

Extreme value theory is quite similar to the central limit theorem and both have common mathematical backgrounds. As the limiting distribution of sample averages is a normal distribution, the limit laws of order statistics are characterized by a class of extreme value theory. This theory deals with asymptotic distribution of maxima without generalizing about the distribution of the whole series. It only studies the tail distribution. Fortunately, analogous to the central limit theorem the limit laws provided by extreme value theory do not require a detailed knowledge of the original distribution that extreme observations belong to. There are two approaches to study the extreme events. One is direct modeling of either maximum or minimum realizations. The other one is modeling of the exceedances of a certain threshold. In this work we focus on the first approach. The first part of the chapter deals with the model formulation and general statements about so called block maxima which can be considered as the cornerstone of the theory. In the next part we introduce a commonly used approach for estimating parameters of extremal distribution.

4.1 Asymptotic models

Let $X_1, \ldots, X_n$ be a sequence of independent random variables with common distribution F. In practice, the series usually represents values of a process measured on a time scale (for instance, daily measurements of rainfall or, as it is in our case, monthly measurements of a economical index) or values of a random process recorded over a predefined time period (for instance, year observations of insurance claims). The theory focuses on the statistical behaviour of block maxima defined as:

$$M_n = \max \left\{ X_1, \ldots, X_n \right\}.$$

It can be easily shown that the exact distribution function of M_n has the form of F^n for all values of n. However, it is not possible to model the distribution function according this formula immediately, since F is an unknown function. One could argue that F could be estimated from observed data and subsequently

used for the distribution function of the block maxima. Nevertheless, this is not an appropriate approach. Even small discrepancies in the estimation of F can cause significant discrepancies for F^n.

The EVT assumes the function F to be unknown and seeks for an appropriate distribution families to model F^n directly. The *Extremal Types Theorem* defines the range of possible limit distributions for normalized block maxima. For convenience we state a modified version of the theorem, the exact formulation and an outline of the proof can be found in Coles (2001).

Theorem 5. *If there exist sequence of constants $\{a_n > 0\}$ and $\{b_n\}$ such that such that*

$$\mathbb{P}\left[\frac{M_n - b_n}{a_n} \leq z\right] \longrightarrow G(z), \qquad n \longrightarrow \infty \qquad (4.1)$$

for a non-degenerate distribution function G, then G is a member of the GEV family

$$G(z) = \exp\left\{-\left(1 + \xi\left(\frac{z-\mu}{\sigma}\right)\right)_+^{-1/\xi}\right\}, \qquad (4.2)$$

where (μ, σ, ξ) are the location, scale and shape parameters respectively, $\sigma > 0$ and $z_+ = \max(z, 0)$.

Remark 6. The fact that the normalizing constants are unknown in practice is irrelevant. Statement 4.1 can be equivalently rewritten as:

$$\mathbb{P}\left[M_n \leq z\right] \approx G\left(\frac{z-b}{a}\right) = G^*(z),$$

where $a = \lim_{n\to\infty} a_n$, $b = \lim_{n\to\infty} b_n$ and G^* is just another member of the same family. Thus the estimation of the parameters of the functions G^* and G involves the same procedure.

The theorem implies that the normalized block maxima converge in distribution to a variable having the distribution function G, commonly termed as the *Generalized Extreme Value* (GEV) distribution. Notable feature of the previous statement is that G is the only possible limit regardless of the original distribution function F.

The GEV family includes three classes of distribution known as the Gumbel, Fréchet and negative Weibull families respectively. Each type can be obtained by a particular choice of the shape parameter ξ. The Fréchet and negative Weibull classes correspond respectively to the case when $\xi > 0$ and $\xi < 0$.The Gumbel class is defined by continuity when $\xi \to 0$. It follows that in practice these

three types give quite different representations of extreme value behaviour corresponding to distinct forms of tail behaviour for the distribution function F of the original data. Consider the upper end-point z_+ of the limit distribution G, i.e., z_+ is the smallest value of z such that $G(z) = 1$. Then for the Fréchet and Gumbel distribution z_+ is infinite, whereas in the case of Weibul distribution it is finite.

Remainder of this section is devoted to the formulation of extreme quantiles estimates. Assume a serie of independent identically distributed random variables $X_1, X_2, \ldots$. Further let us split the sequence into blocks of length n, for some large n, and generate a series of maxima corresponding to each block, to which the GEV distribution can be fitted. Then by inverting Equation 4.1 we arrive to the following expression for extreme quantiles:

$$q_p = \begin{cases} \mu - \frac{\sigma}{\xi} \left(1 - (-\log(1-p))^{-\xi} \right), & \text{for } \xi \neq 0, \\ \mu - \sigma \log\left(-\log(1-p) \right), & \text{for } \xi = 0, \end{cases} \tag{4.3}$$

where $G(q_p) = 1 - p$. q_p from the previous equation is commonly termed as the *return level* associated with the *return period* $1/p$. The quantile q_p can be interpreted as a value that is exceeded by the maximum in any relative period with probability p. Quantile analysis enables to express stochastic models on the scale of observed values, therefore it provides illustrative interpretation. In particular, if q_p is plotted against $y_p = -\log(1-p)$ on a logarithmic scale, the plot is linear in the case $\xi = 0$, convex with asymptotic limit for $\xi < 0$ and concave without any finite bound for $\xi > 0$. The graph is called a *return level plot* and indicates whether the fitted distribution resemble rather Gambel, Fréchet or negative Weibul.

4.2   Inference procedure

Behaviour of block maxima can be described by distribution in the spirit of Theorem 5. Its application involves blocking the data into sequences of equal length, determining the maximum for each block and fitting the GEV distribution to such specified values. It has been shown that determining the block size can be the crucial issue. Large blocks generate few maxima, which leads to large variance in parameters estimation and subsequently the accuracy of fitted distribution. On the other hand if the blocks are too small, the set of block maxima includes values that are rather usual than extreme. Then the limit distribution stated in Theorem 5 is likely to be poor. Thus the choice of the length for block is the trade-off between bias and variance. Although some statistical methods can be derived, in practice the length corresponds to a reasonable time unit, for instance annual maxima are often applied.

If the appropriately normalized sample maxima converge in distribution to a non-degenerate limit G given in Formula 4.2, the cumulative distribution function F is said to be in the *domain of attraction* of the generalized extreme value distribution G. The class of distributions for which such an asymptotic behavior holds is large. Several estimators of the tail index α, i.e., the reciprocal value of the shape parameter ξ, and of the shape parameter ξ itself have been studied in the literature. We present here the main one, the Hill estimator, which is by far the most used. Hill (1975) constructed a classic tail index estimator for the Frechét type distribution (i.e. $\xi > 0$), which has a power law form with regularly varying tails,

$$1 - F(x) \approx x^{-\alpha} L(x), \qquad \alpha > 0, \tag{4.4}$$

where α is the tail index and $L(x)$ is a slowly varying function, i.e.,

$$\lim_{x \to \infty} \frac{L(tx)}{L(x)} = 1, \qquad \forall t > 0,$$

which allows flexibility in the lower tail but at the same time ensures the power law behavior dominates the upper tail. Clearly, this model does not have such flexible upper tail since it reduces distribution to the case when $\xi > 0$. However it is an important special case in many financial applications. Formula 4.4 is often taken as a definition of *heavy-tailed* distributions; Pareto, Burr, log-gamma, and Cauchy distributions, as well as various mixture models present this characteristic. The Hill estimator often outperforms other estimators as far as we are concerned in the estimation of the tail index, i.e. in the case when our cumulative distribution function is in the maximum domain of attraction of a Fréchet distribution. Otherwise the Hill estimator does not work and one has to employ some other estimator. This is not usually a major issue, since, as already noticed, many financial time series have an extreme value distribution of Fréchet type and the strong connection between the tail index and the parameters of stable laws and the Student t distribution (a Student t distribution satisfies Formula 4.4 with α equal to its degrees of freedom) explains why the earliest applications of extreme value distribution to finance were especially focused on estimating the tail index.

A wide range of techniques has been developed so far for the tail index and the tail fraction estimation. In this thesis we present an approach based on the $k+1$ upper order statistics (for more datailed description see Scarrott and MacDonald (2012)). Consider a sequence of raw data $x_1, \ldots, x_n$ as realizations of independent and identically distributed random variables $X_1, \ldots, X_n$. Let $x_{1:n}, \ldots, x_{n:n}$ represent the data in decreasing order. The Hill estimator for the tail index $\alpha = \xi^{-1}$ based on the $k+1$ upper order statistics,

$$\hat{\xi}_{k,n}^{H} = \frac{1}{k} \sum_{j=1}^{k} \log x_{j:n} - \log x_{(k+1):n}, \tag{4.5}$$

is the estimate of the reciprocal value of the constant for the slowly varying function in Approximation 4.4, i.e. it is the estimate of $1/\alpha = \xi$ (for the exact derivation see Appendix A).

The Hill estimator has undergone both deep theoretical study and intensive application, displaying very good performance, competitive (and in some cases even superior) with respect to other extreme value theory approaches. From a theoretical viewpoint, the favourable consideration towards the Hill estimator is justified by its asymptotic properties (see Embrechts, Klüppelberg, and Mikosch (1997))

- *weak consistency*: $\hat{\alpha}_{k,n}^H \xrightarrow{P} \alpha$ for $k, n \to \infty$, $k/n \to 0$,

- *strong consistency*: $\hat{\alpha}_{k,n}^H \xrightarrow{a.s.} \alpha$ for $k \to \infty$, $k/n \to 0$, $k/\ln(\ln n) \to \infty$,

- *asymptotic normality*: $\sqrt{k}\left(\hat{\alpha}_{k,n}^H - \alpha\right) \xrightarrow{d} N(0, \alpha^2)$.

Note that the last statement holds only under additional hypothesis.

The resultant estimate of parameter α based on the Hill approach is critically dependent on the tail fraction chosen. By virtue of Formula 4.5, these estimates are expected to change with decreasing values of k. The Hill plot, explored by Drees, de Haan, and Resnick (2000), is a graphical diagnostic for prior determination of the tail fraction, which plots the Hill estimator for a range of values of k against either k, thus the Hill plot consists of points

$$\left\{\left(k, \hat{\alpha}_{k:n}^H\right) : k = 2, \ldots, n\right\}, \tag{4.6}$$

where $\hat{\alpha}_{k:n}^H = (H_{k:n})^{-1}$. The value of k is chosen as the largest value (i.e., lowest threshold) such that the Hill estimator has stabilized. The obvious benefit of the Hill plot consists in illustrative simplicity, on the other hand it suffers from many drawback. Mainly, the Hill estimator can exhibit substantial bias if the slowly varying component $L(x)$ decays slowly in the limit.

Various authors have investigated automated approaches to determining the tail fraction by, for example, minimizing the mean square error of estimators of properties of the tail distribution, such as the tail index, the quantiles, or the tail probabilities, for which optimal asymptotic results typically require second order assumptions in addition to Approximation 4.4. Even if the assumptions underlying these approaches are appropriate, their major drawback is that they do not account for the threshold uncertainty on subsequent inferences. The need to estimate parameters of the unknown population distribution F prior to determination of the optimal tail fraction (e.g., tail index or second order characteristics) has led to the utilization of alternative statistical approaches such as bootstrap or Monte Carlo simulation. The secondly mentioned method was prioritized by Haile and Pozo (2006) in their study exploring an impact of exchange regime on the vulnerability to currency crises. Monte Carlo experiments were used to find

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the level of k conditional upon a sample size n and distribution function $F(x)$, for which the mean squared error of the Hill estimator is minimal. In our computational experiment we use very simple, traditional approach to identifying the tail fraction which has been used since the first construction of the Hill estimator. Hill (1975) suggested using the fact that the log spacings between the order statistics should be exponentially distributed under the Pareto tail assumption in choosing the tail fraction (note that this assumption is satisfied since we assume that the maximum of exchange market pressure converges to Fréchet distribution and thus distribution of exceedances of exchange market pressure over a high threshold is member of the Pareto family). Thus his approach involves finding the maximum k such that $\left\{ \log x_{j:n} - \log x_{(k+1):n} \ : \ j = 1, \ldots, k \right\}$ does not fail a exponentiality test (e.g., a Kolmogorov–Smirnov or any similar test). As it was already mentioned in the previous text, a propriate estimate of the tail index α is obtained if only the correct tail observations, given by k, are considered. If we choose too few observations, we will obtain inefficient parameter estimates. On the other hand, if we choose too many observations, the parameter estimates will be biased as a result of including nontail observations.

5. Computational results

This section is devoted to the presentation and discussion of the computational experiments carried out to assess and validate technique of currency crises identification exploiting extreme value theory. Firstly, we refer to Appendix B for a brief overview of exchange rate regimes in the selected sample of countries (Czech Republic, Hungary, Poland and Slovakia). The following chapter itself provides a data description together with a discussion on development of exchange rates and foreign exchange reserves refering to the previously mentioned exchange rate regime changes. The last but the most extensive part focuses on calculation of exchange market pressure and currency crises identification. In particular, we employ the Hill method to estimate the appropriate threshold for identification of exceedances which are associated with currency crises occurrences.

Remark 7. All calculations are carried out using software R (version 3.0.0). Although there is package `evir` which implies functions for extreme value theory, in particular it includes function implementing the Hill estimator, we declare our own procedures in order to implement exact approach to tail fraction selection presented in the previous chapter.

5.1 Data description

An important basis for research on exchange market pressure and its usage for currency crisis identification is the availability of data source. Data set used in the computational experiment was collected by the Czech National Bank, which on monthly bases recorded macroeconomic indicators of 185 countries in the world since January 1993. The file includes information about the quantity of foreign exchange reserves, nominal exchange rates, real effective exchange rates, consumer price index change and money market rates. Taking into account the exact formulation of our exchange market pressure index, we are solely interested in development of exchange rate and foreign exchange reserves related to the selected sample of countries. We recall that the sample consists of four central European countries, former member of the Soviet Union (the Czech Republic, Hungary, Poland and Slovakia). We particularly intend to investigate the exchange market pressure during January 1993 and December 2012, in the case of Slovakia the period of our interest ends with its integration to European Monetary Union in December 2008 through which the country lost monetary autonomy.

Development of exchange rates of the Czech crown, Hungarian forint, Polish zloty and Slovakian crown (quoted in the unit of special drawing rights) are displayed in Figure 5.1. We observe very similar features in development of these currencies.
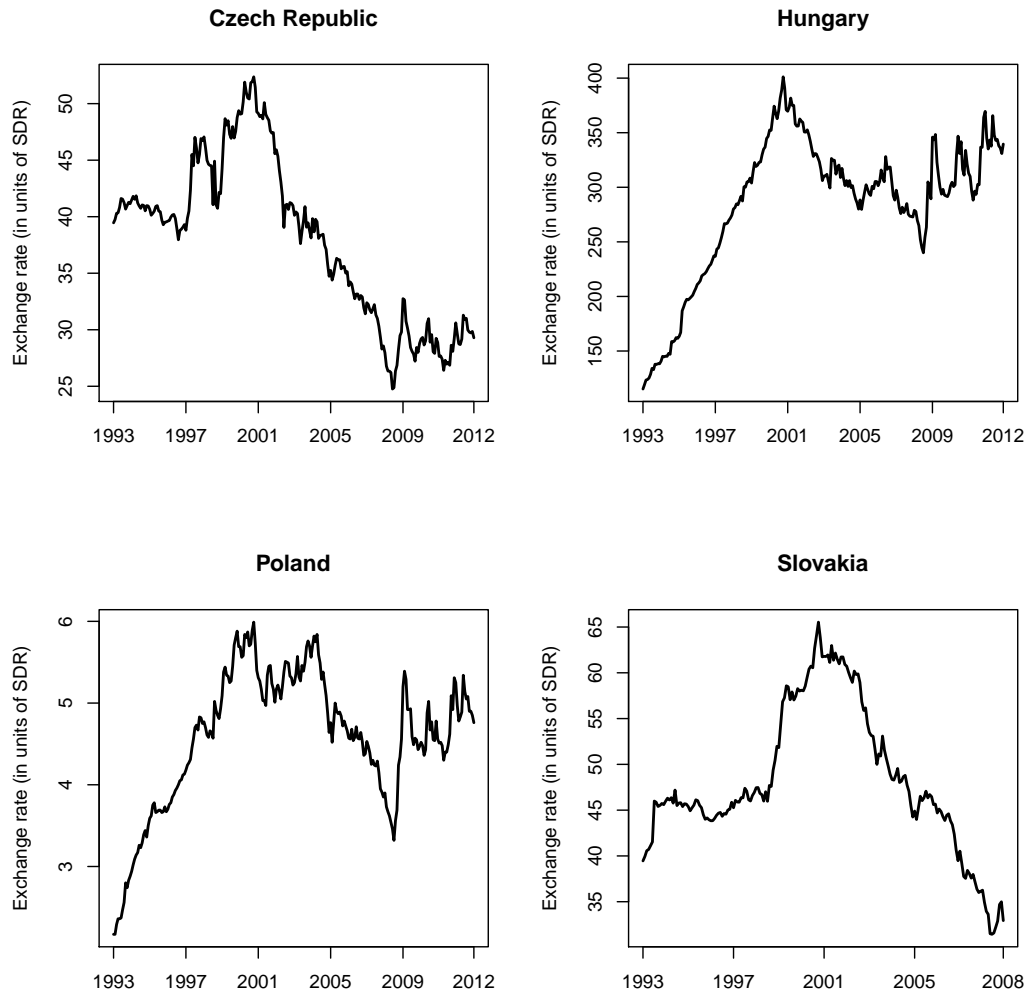
Figure 5.1: Development of exchange rate (in units of SDR) in the Czech Republic, Hungary, Poland from January 1993 to December 2012 and Slovakia from January 1993 to December 2008 (monthly data).

The first phase, bounded by year 2000, can be characterized by coherent depreciation resulting from former situation. In principle, after 45 years of centrally planned policy, considered countries were unsuited for integration into a market driven economies. In the first years of transition reforms the inflation rates were extremely high and constantly rising, which created very unstable conditions. The majority state-owned monopolies and holdings were largely ineffective and completely obsolete in terms of technologies, which dramatically reduced competitiveness with respect to western European countries. Since the completion of reforms the economic environment with resulted in currencies appreciation.
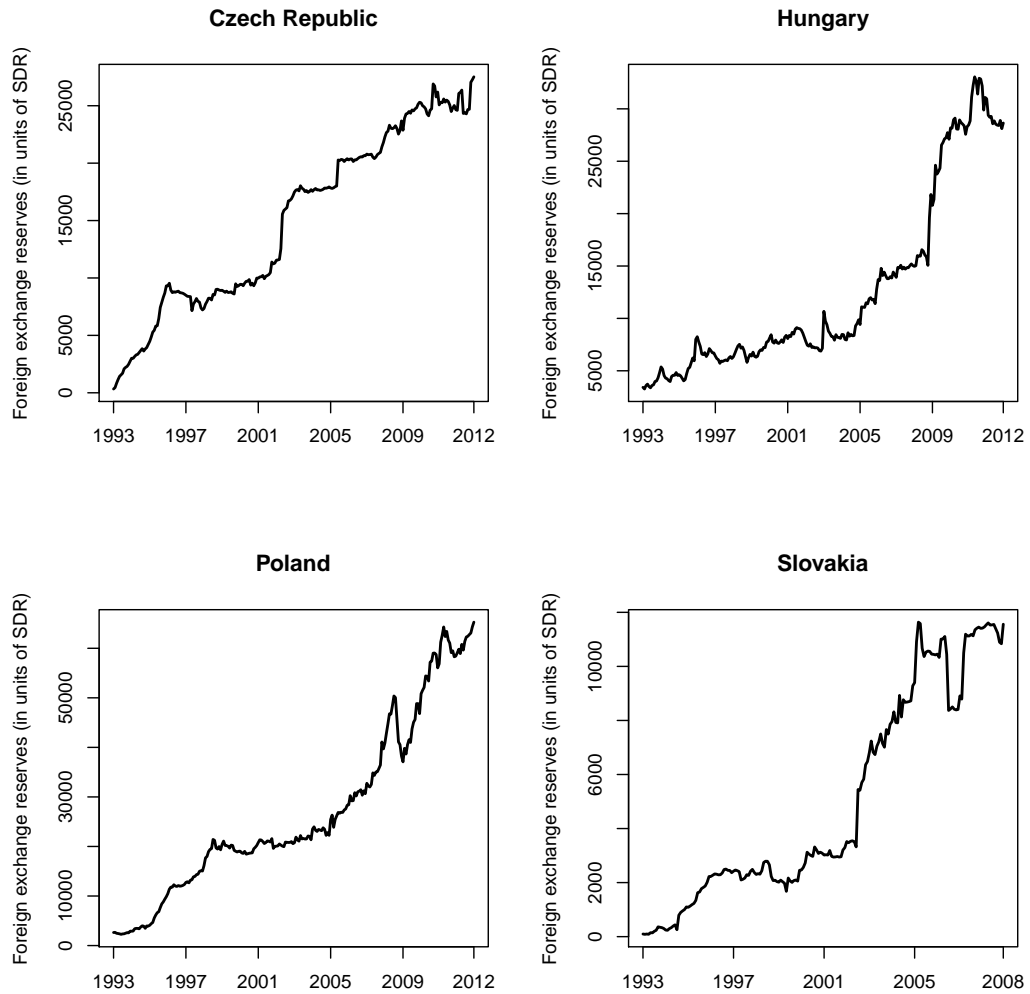
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Figure 5.2: Development of foreign exchange reserves (in units of SDR) in the Czech Republic, Hungary, Poland from January 1993 to December 2012 and Slovakia from January 1993 to December 2008 (monthly data).

The long lasting appreciation was then interrupted by the global financial crisis of 2008, when all considered currencies sharply depreciated again (with the exception of Slovakia crown which became extinct with country's integration into European Monetary Union). In the end, we provide a brief descriptive statistics. The highest monthly depreciation occurs at the end of 2008 or at the beginning of 2009, the Czech crown depreciated by almost 10%, Hungary even by almost 20% within one month horizon. Polish zloty depreciated at maximum by 14.91% at the end of 2008. Similarly, the highest monthly appreciations were recorded in late 2009 and 2010 (appreciation fluctuated around 7%).

Figure 5.2 depicts development of foreign exchange reserves in the units of special drawing rights of four central European countries. Since the beginning of the transition reforms, the national banks accumulated foreign exchange reserves primarily in order to execute independent exchange rate regime. As we can observe, this phenomenon has persisted over all period of our interest to the present. While in the Czech Republic and Poland, the foreign exchange reserves have accrued linearly, in the case of Hungary and Slovakia we recognize rather quadratic trend. As in the previous case, we provide a brief descriptive statistics of change in foreign exchange reserves. Firstly, let us note that the sequence of monthly differences predominantly consists of positive values. Whereas declines in reserves are negligible, appearing especially at the beginning of examined period and reaching at maximum 10%, increases reach up to hundreds of percentage (for instance, Slovakian reserves rose by 210% in August 1994). Comparing the first and the last observation, we find that the reserves of the Czech Republic multiplied by 8200%, those of Slovakia even by 11700% (in the case of Hungary and Poland the reserves increased by 740%, or 2400% respectively). However, we have to keep in mind that the initial reserves at the beginning of transition reforms were practically negligible which substantially influenced the results.

Remark 8. (On special drawing rights). Special drawing rights are supplementary foreign exchange reserve assets defined and maintained by the International Monetary Fund. They were created in 1969 in order to supplement a shortfall of preferred foreign exchange reserve assets, namely gold and the US dollar. The value of a SDR is defined by a weighted currency basket of four major currencies: the US dollar, the euro, the British pound, and the Japanese yen. Not a currency, SDRs instead represent a claim to currency held by International Monetary Fund member countries for which they may be exchanged. As they can only be exchanged for euros, Japanese yen, pounds sterling, or US dollars, special drawing rights may actually represent a potential claim on member countries' nongold foreign exchange reserve assets, which are usually held in those currencies.

5.2 Data analysis

This part of the computational results presents estimates of exchange market pressure of our sample countries calculated in the spirit of Formula 3.18. In the first step, we try to link features of exchange market pressure developments to particular exchange rate and monetary regimes or their changes. In the second step, we view series of exchange market pressure as statistical observation and exploit their statistical characteristics and distribution. The last part of the section is devoted to identification of currency crisis applying the Hill method and its comparison to the classical crisis identification suggested by Eichengreen, Rose, and Wyplosz (1995) (see Formula 3.15).

5.2.1 Exchange market pressure estimation

To evaluate exchange market pressure correctly it is necessary to remember two elementary facts. Firstly, a negative value of exchange market pressure indicates that the currency is under general pressure to appreciate. On the contrary, positive values shows that the currency is pressured to depreciate. Let us recall that a currency crisis is defined as a speculative attack on the foreign exchange value of a currency that either results in a sharp depreciation or immense by selling foreign exchange reserves or raising domestic interest rates. Thus we are concerned with periods with positive values of exchange market pressure, since we are interested in currency crises periods. Secondly, the value of exchange market pressure represents the magnitude of the foreign exchange market disequilibrium, which should be removed by a respective change of the exchange rate.

Figure 5.3 displays exchange market pressure development in four central European countries, which can be characterized by many similar aspects. Considering the Czech Republic, no extraordinarily volatile development of exchange market pressure can be observed in the first three years of the period examined. Far from it, the development in the Czech Republic over that period of time was one of the most stable ever. On contrary, development of exchange market pressure in Hungary, Poland and Slovakia in the first years can be characterized by many episodes of excessive exchange market pressure and its high volatility. Whereas in the case of Hungary and Slovakia, the estimates suggest that there was a general pressure on these currencies to depreciate, the principal exception was Poland, whose nearly 60% (58.3%) of exchange market pressure measurements lie on the appreciation side in during 1993 - 1995. As Stavárek (2008) pionts out, it is very hard to believe that the magnitude of money market disequilibrium would be so enormous that the Polish zloty should have appreciated by 60% in order to remove that disequilibrium. He addresses the unusual observation to a beginning stage of the transformation process. It is worthwhile to remember that all four countries applied some version of fixed exchange rate regime in 1993 - 1995. Furthermore, the Czech Republic and Slovakia started their existence in January 1993 after the split of the former Czechoslovakia. The related currency separation, launch of new currencies, establishment of new central banks, and formation of new monetary policies had an impact on data used in the estimation.

Considering development of exchange market pressure index between 1996 and 2008, we could divide examined countries into two groups. One consists of Slovakia and Poland, for which we observe smooth series free of any abnormal fluctuations. Moreover, Slovakia was not exposed to any speculative attacks characterized by sharp depreciation pressure even during the period of peg (November 2005 - December 2008), which was required for joining the European Monetary Union. The Czech Republic and Hungary, on the other hand, experienced more or less extensive attacks on their currency. We observe strong depreciation pressure
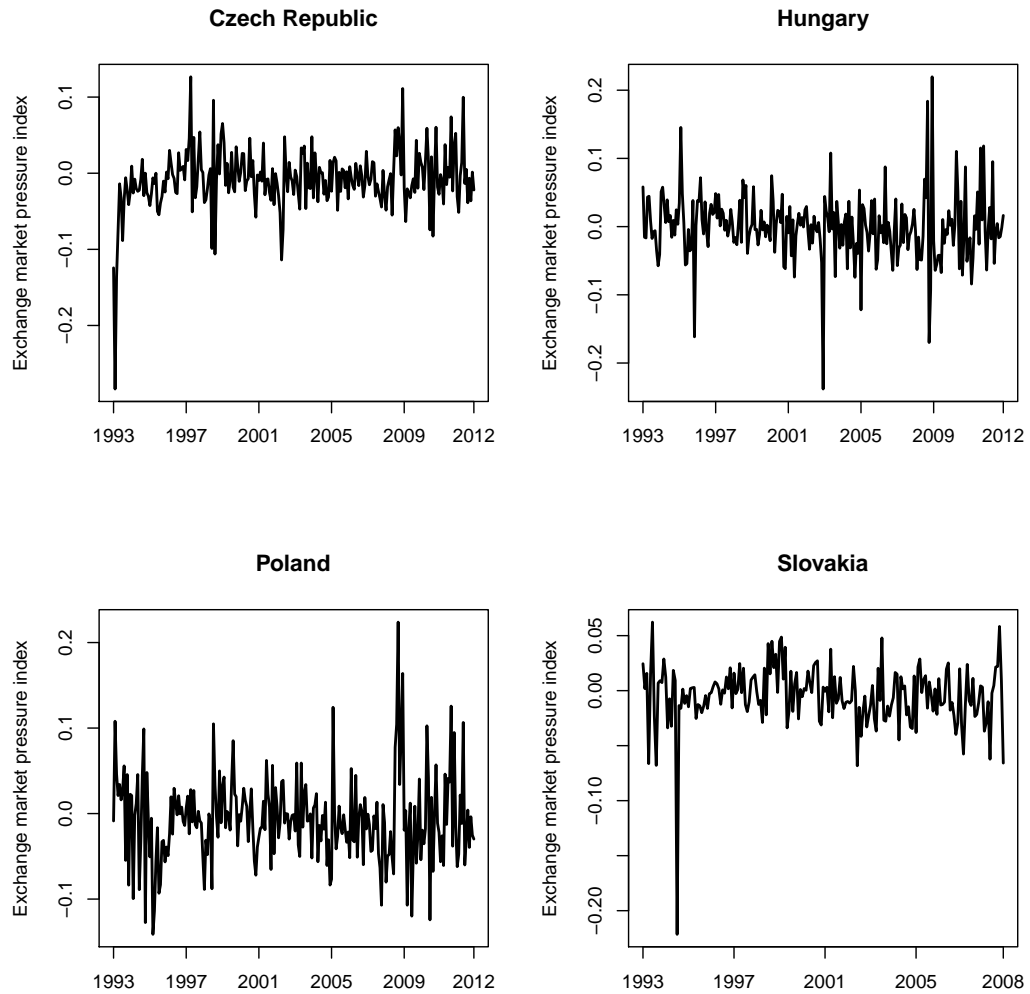
Figure 5.3: Exchange market pressure development in the Czech Republic, Hungary, Poland from January 1993 to December 2012 and Slovakia from January 1993 to December 2008 (monthly data).

on the Czech crown in 1997 which in the end forced monetary authorities to leave intermediate exchange rate regime and accept managed floating. Development of Hungarian exchange market pressure index can be characterized as the most oscillating and unstable. Whereas there were depreciation pressures on the forint at the end of 1995, very low index in 2002 suggests a pressure to appreciate. A high, but not excessive, exchange market pressure also occurred at the end of 2002. Hungary was under speculative attack on the upper edge of the band followed by monetary authority, which culminated in devaluation of the central parity.

The last period examined here (2008 - 2012) does not refer to Slovakia anymore, since Slovakia became a member of European Monetary Union at the beginning of January 2009. For the rest of the countries we can observe very dramatic movements of exchange market pressure beginning at the end of the year 2007, which can be considered as signals of forthcoming financial crisis. Generally, financial crises are often associated with significant movements in exchange rates, which reflect both increasing risk aversion and changes in the perceived risk of investing in certain currencies. However, exchange rate movements during the global financial crisis of 2007 - 2009 were unusual. Unlike in two previous episodes, the Asian crisis (1997 - 1998) and the crisis following the Russian debt default (1998 - 2008), a large number of currencies depreciated sharply even though they were not at the center of the crisis. Moreover, during 2009, the movements related to the crisis reversed strongly for a number of countries. These developments were probably contributed by two factors. First, during the latest crisis, safe haven effects went against the typical pattern of crisis related flows. Capital typically flees the crisis country and moves into safe haven currencies. During the most recent crisis, however, safe haven countries, for instance, the United States, were most affected by the crisis. Second, comparing the latest crisis with two earlier crisis episodes, we find that the role of short-term interest rate differentials in both the depreciations and their reversal has grown over time, perhaps reflecting the increasing role of carry trades in exchange rate movements.

In the second kind of comparison we focus on magnitude of behaviour of exchange market pressure time series. This can be documented by descriptive statistics presented in Table 5.1 and probability density accompanied by histogram displayed in Figure 5.4. From the firstly mentioned table we see that all means as well as all medians have negative sign. If we consider difference between these two characteristics for each series separately, we can conclude, that its distribution is rather centered taking into account the scale determined by positions of the first and third quantiles. The highest volatility of exchange market pressure expressed by standard deviation is attributed to Poland, followed closely by Hungary. However, even these volatilities are not particularly high judging by the previously mentioned scale of the estimated values. This conclusion can be supported graphically by Figure 5.4, the central part of each distribution is considerable narrow and peaked.

Inspection of the exchange market pressure series indicates that the data do not conform to the normal distribution, they seem to follow leptokurtic distribution. The center part of the distribution is more peaked, there is greater mass in the tails in comparison with standard normal distribution, and there are fewer observations in the intermediate ranges of the distribution. Thus excess kurtosis suggests that the data have rather fat tails which fall asymptotically within the Fréchet distribution and can be estimated using the Hill method.
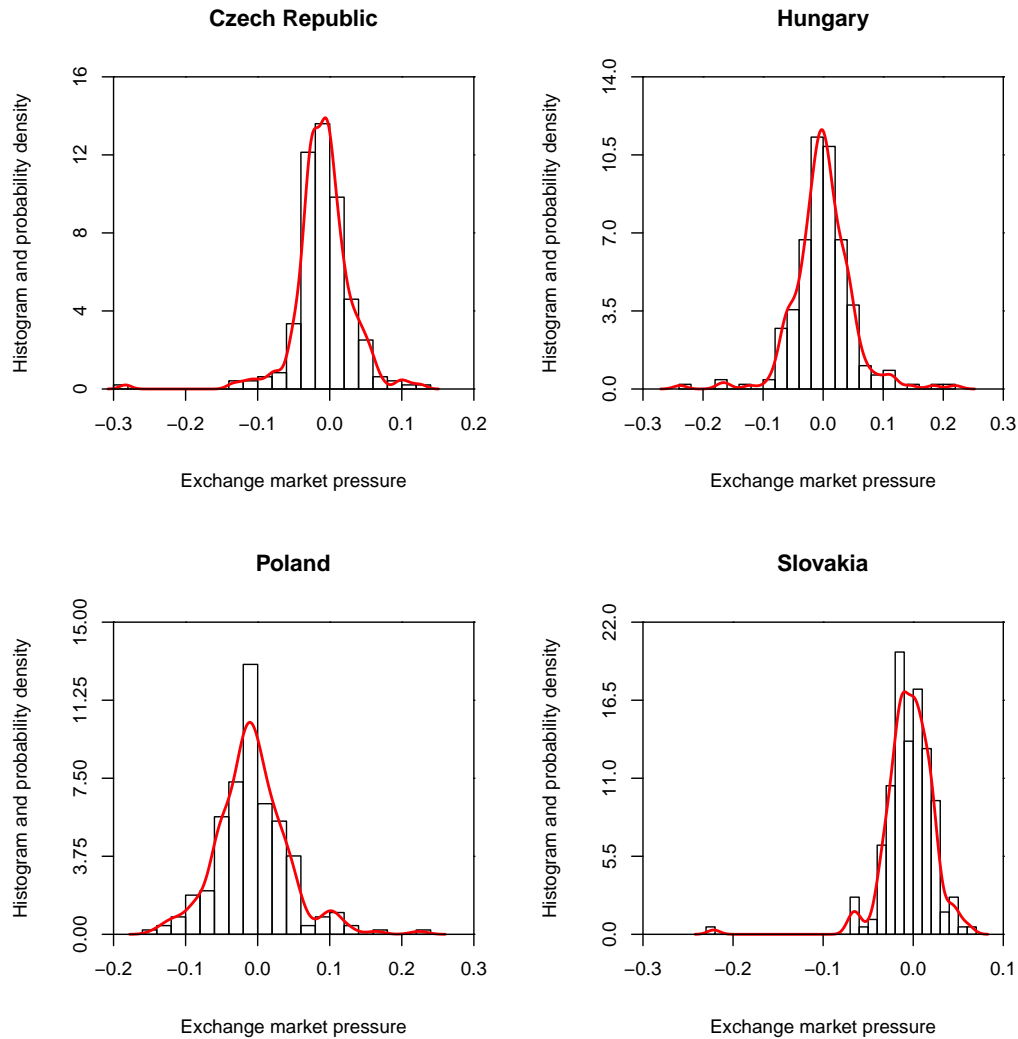
Figure 5.4: Probability density and histogram of exchange market pressure index in the Czech Republic, Hungary, Poland from January 1993 to December 2012 and Slovakia from January 1993 to December 2008 (monthly data).

5.2.2 Currency crisis identification

In order to compare deterministic methodology of currency crisis identification with presented stochastic approach, we first implement the crisis criterion as suggested in the majority of papers on currency crisis identification. Namely, we use a binary variable designed by Eichengreen, Rose, and Wyplosz (1995) which marks as currency crisis periods those time intervals for which its exchange market pressure index exceed a fixed deterministic value, usually the value is set as the mean of corresponding exchange market pressure series increased by multiple of

	Czech Rep.	Hungary	Poland	Slovakia
minimum	-0.2834	-0.2381	-0.1412	-0.2215
1st quantile	-0.0263	-0.0246	-0.0345	-0.0170
median	-0.0082	-0.0026	-0.0101	-0.0023
mean	-0.0083	-0.0004	-0.0072	-0.0046
3rd quantile	0.0097	0.0236	0.0196	0.0121
maximum	0.1266	0.2196	0.2238	0.0622
standard deviation	0.0399	0.0485	0.0498	0.0279
skewness	-1.2411	0.0198	0.6318	-2.4569

Table 5.1: Descriptive statistics of exchange market pressure index in the Czech Republic, Hungary, Poland from January 1993 to December 2012 and Slovakia from January 1993 to December 2008 (monthly data).

its standard deviation (for exact expression see Formula 3.15).

Results of currency crisis identification described in the previous paragraph are presented in Figure 5.5. Bars represent exchange market pressure values for monthly data, red ones than denote identified currency crisis periods. In addition, legends situated in bottom-right corner of each graph provide information about number of observations marked as currency crisis periods as well as number of observations whose values did not exceed the threshold. From the presented graphs we can observe that currency crisis periods occupy approximately 5% of observation with the highest exchange market pressure. These results are nowise surprising, samples of exchange market pressure are not considerably skewed and standard deviations are very similar, thus the number of exceedances above the threshold determined by the sum of mean and multiple of standard deviation cannot differ significantly through samples. However, from the shapes of emipircal densities (Figure 5.4) it is obvious, for instance, than the distribution of exchange market pressure of Slovakia is considerable narrow in comparison with distribution of Hungary and tend to have rather normal tails, on the other hand the distribution of Hungary seems to have fat tail. Thus we would expect that the ratio of cuccency crisis periods to overall number of observations would be higher in the case of Hungary in comparison with Slovakia. Previous conclusion therefore forces to use stochastic approach when identifying currency crisis periods as tail observations.

Generally, our immediate objective is to determine the number of extreme values k for exchange market pressure and then to use these to define periods of currency crisis. These k observations are then identified and matched to their corresponding time periods, yielding us periods of crisis. The only question is how to find the optimal number k.
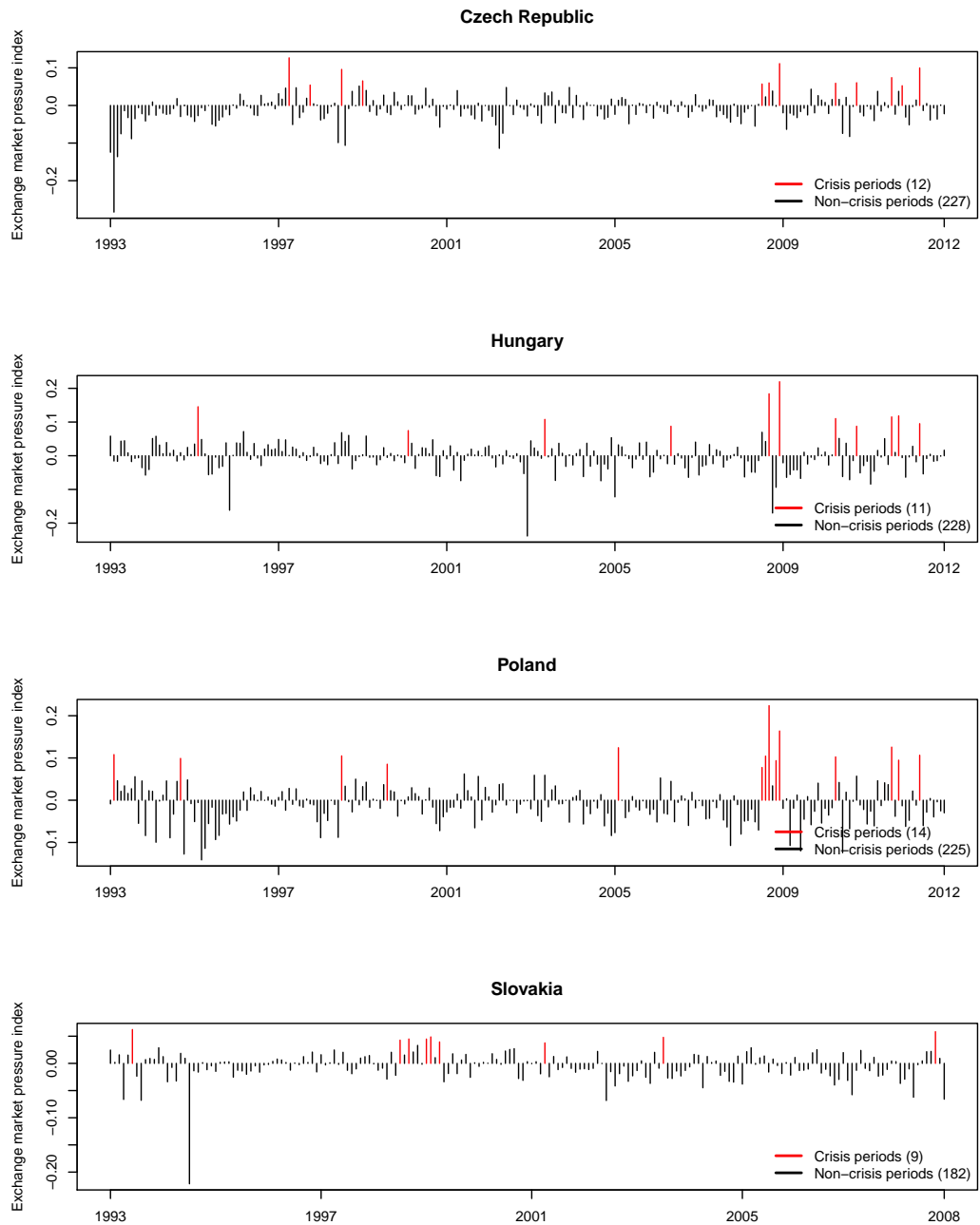
Figure 5.5: Deterministic currency crisis identification for the Czech Republic, Hungary, Poland from January 1993 to December 2012 and Slovakia from January 1993 to December 2008 (monthly data).

In the stochastic approach for currency crisis identification we aim to approximate the maximum of exchange market pressure by generalized extreme value

distribution and consequently use its shape parameter ξ, or its tail index α respectively, for identification of tail observations which correspond to currency crisis periods. In order to estimate the tail index we employ the Hill method, whose theoretical background is explained in Chapter 4 and Appendix A. In this part, we only recall the most important milestones that are essential for computational implementation.

Suppose we have a sequence of exchange market pressure values $x_1, \ldots, x_n$ of length n. We additionally assume that they are realizations of independent and identically distributed random variables. Let us denote as $x_{1:n}, \ldots, x_{n:n}$ the observations in descending order. The Hill estimator for the tail index $\alpha = \xi^{-1}$ based on the $k + 1$ upper order statistics is given as the reciprocal value of the following estimate (Formula 4.5)

$$\hat{\xi}^H_{k,n} = \frac{1}{k} \sum_{j=1}^{k} \log x_{j:n} - \log x_{(k+1):n}.$$

First of all, it is necessary to be aware of the logarithmic transformation of the original sequence. However the logarithmic function is defined only on interval $(0, \infty)$, thus we have to reduce the sequence of exchange market pressure to all positive observations. Note that this is not a restrictive assumption since we are interested only in positive extreme values of exchange market pressure and the tail index is based on a few right tail observations.

In the second step we try to seek for the optimal tail fraction determined by number k. For this purpose we balance findings stemming from the Hill plot as well as those provided by the statistical tests. Let us recall that the Hill plot is defined by the following set of points (Formula 4.6)

$$\left\{ \left(k, \hat{\alpha}^H_{k:n} \right) : k = 2, \ldots, n \right\}.$$

The value of k is then chosen as the largest value such that the Hill estimator has stabilized. As mentioned in the theoretical part, the obvious benefit of the Hill plot consists in illustrative simplicity, on the other hand it is only an auxiliary tool. Thus even there is a significant stabilizing index we cannot make any conclusions about the desired tail index value without executing any relevant statistical test. Therefore we implement very simple, traditional approach suggested by Hill (1975). In his research he proved that that the log spacings between the order statistics follow exponential distribution on the condition that tail observations have Pareto distribution. Conclusions made in the previous subsection lead to conviction that data have rather fat tails which fall asymptotically within the Fréchet distribution due to excess kurtosis. If we assume that the maximum of exchange market pressure converges to Fréchet distribution then distribution of exceedances of exchange market pressure over a high threshold is member of the Pareto family and therefore the procedure suggested by Hill (1975) appears to

be an adequate tool for tail index estimation. The method itself involves finding the maximum k such that $\{\log x_{j:n} - \log x_{(k+1):n} : j = 1, \ldots, k\}$ does not fail a exponentiality test. Note that for $k = 1, 2$ the sequence of log differences consists of only 1 and 2 observations, thus it is very likely that the zero hypothesis of exponential distribution cannot be rejected for these cases. If, however, the same hypothesis is rejected for higher k, it is reasonable to assume that the original data do not follow any fat-tailed distribution. In other words, exchange market pressure development can be considered as relatively smooth any therefore the corresponding country can be characterized by stable currency. In the practical implementation we apply Kolmogorov - Smirnov test.

Remark 9. Assume $x_{1:n} \leq x_{2:n} \leq \cdots \leq x_{n:n}$ to be a sample in ascending order with a common distribution function F. The Kolmogorov-Smirnov statistics measures the maximum deviation of the empirical distribution function and the fitted distribution function, it is defined as:

$$
\begin{aligned}
D^+ &= \max_{1 \leq j \leq n} \left\{ \frac{j}{n} - \hat{F}\left(x_{j:n}\right) \right\} \\
D^- &= \max_{1 \leq j \leq n} \left\{ \hat{F}\left(x_{j:n}\right) - \frac{j-1}{n} \right\} \\
D &= \max\left\{ D^+, D^- \right\}.
\end{aligned}
$$

The hypothesis regarding the distributional form is rejected if the test statistic, D, is greater than the critical value obtained from a table. There are several variations of these tables in the literature distinguishing by different scalings for the test statistics and critical regions. These alternatives are provided by software programs that perform the test.

Since the whole estimating process has been explained, we can move to presentation of obtained results. Table 5.2 summarizes outputs of the procedure seeking for the maximum k such that the sequence of log differences does not fail the exponential distribution. In the first row of the table there are estimates of k for which the previous statement holds true (for convenience we denote this k by symbol k^*), the send line then contains corresponding tail indices for all considered countries. We only comment on parameter k since the exact value of the tail index is irrelevant in our analysis, as it will be shown later. Whereas the exponential distribution of log differences fails after k reaches 8 or 7 in the case of the Czech Republic and Poland, in the case of Slovakia the maximum k equals to 2 and for Hungary, on the contrary, the maximum k equals to 22. These results are consistent with the conclusions made on the basis of empirical densities and descriptive statistics, i. e., the density of Hungarian exchange market pressure have fat tail and thus we identify higher number of tail observations, the density of Slovakian exchange market pressure, on the other hand, is close to normal distribution and there should be few tail observations, if any. Figure 5.6 displays
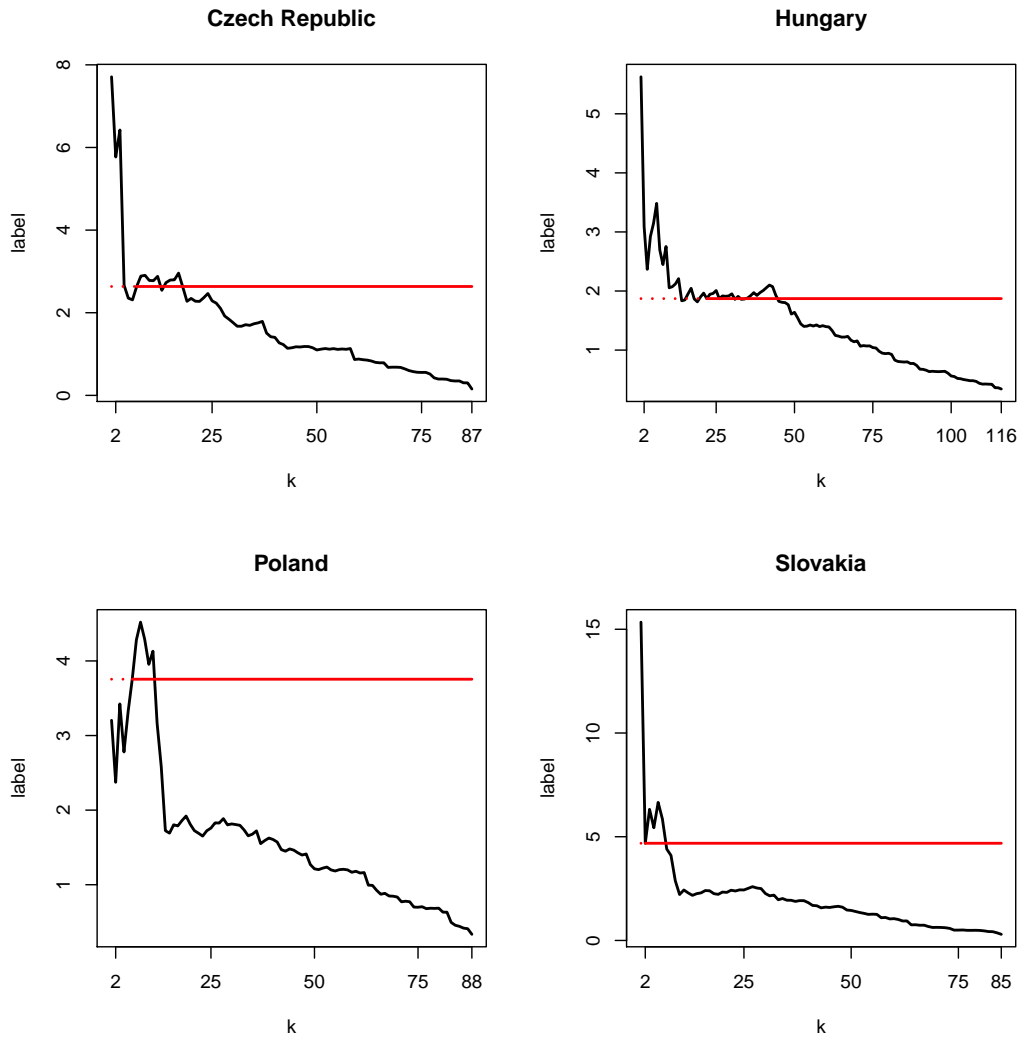
Figure 5.6: Hill plots supplemented by tail index estimates for the Czech Republic, Hungary, Poland from January 1993 to December 2012 and Slovakia from January 1993 to December 2008 (monthly data).

the Hill plots which are accompanied by results from Table 5.2. We can see that the Hill plots do not provide any relevant information, there are no stabilizing tendencies with increasing value of k and potential estimates of the tail index decrease for all $k = 1, \ldots, n^*$, where n^* denotes number of positive observation of a sequence of exchange market pressure. The levels of the red lines correspond to the estimates of the tail indices stated in Table 5.2, while dotted part of the line corresponds to $k = 1, \ldots, k^*$ and continuous part to the rest. It is obvious that the methods lead to inconsistent findings. Nevertheless, as we emphasized before, the Hill plot can be considered only as a illustrative tool and is not statistically

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conclusive, we expend further considerations in the spirit of results obtained from the first procedure.

	Czech Rep.	Hungary	Poland	Slovakia
k	7	22	6	2
$\hat{\alpha}_{k:n}^{H}$	2.6355	1.8715	3.7550	4.6847

Table 5.2: Tail index estimates for the Czech Republic, Hungary, Poland from January 1993 to December 2012 and Slovakia from January 1993 to December 2008 (monthly data).

We have already estimated the tail indices of the distributions, thus in the last step it remains to identify abnormally large observations which define currency crisis periods. These observations can be associated with the tail fraction of the distribution. We note, that the tail fraction of a distribution behaves differently in statistical sense than the rest of the observations, as it was explained in Chapter 4. Both previous methods related to identification of the optimal Hill estimator can be alternatively understood as tools for determining the tail fraction of a distribution. For clarity, take the case of the Czech Republic, for instance. According to Table 5.2, k equals to 7, thus the optimal tail index is estimated based on seven largest observation (this conclusion is made with respect to the fact that logarithm is continuous, strictly increasing function). In other words, seven largest observations can be attributed to extreme behavior of exchange market pressure and thus are evidences of currency crisis.

Figure 5.7 displays currency crisis periods stemming from the application of statistical approach for their identification. The graphs are analogous to Figure 5.5, thus the bars represent exchange market pressure values for monthly data, red ones than denote identified currency crisis periods. The legends again provide information about number of observations marked as currency crisis periods (there numbers correspond to the length of the tail fraction k) as well as number of observations whose values did not exceed the threshold. From the graphs we observe that currency crisis periods do not occupy constant part of observation with the highest exchange market pressure anymore, as it happened when applying the deterministic approach. To those countries, whose distributions of exchange market pressure have more significant fat tails, the methodology assigns higher number of currency crisis periods. This is the case of Hungary, for which we identify 22 currency crisis periods. Conversely, countries, whose distributions of exchange market pressure have rather normal tails, experience less currency crisis periods. As an example we state Slovakia, which according to the mathematical model underwent two crisis periods. Thus we can conclude that the stochastic approach performs better than the deterministic one.
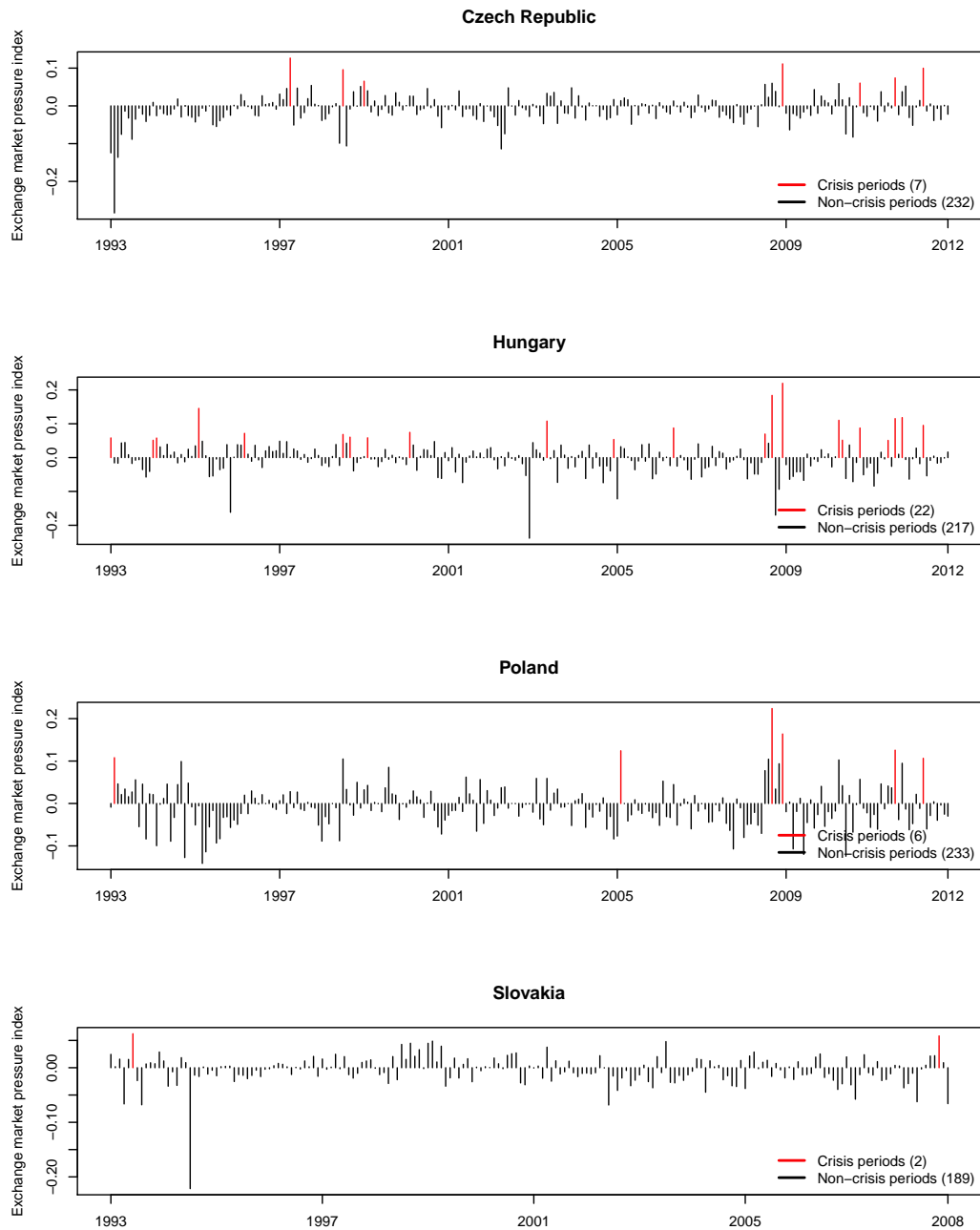
Figure 5.7: Stochastic currency crisis identification for the Czech Republic, Hungary, Poland from January 1993 to December 2012 and Slovakia from January 1993 to December 2008 (monthly data).

We have discussed the accuracy of classical and statistical currency crisis identification from the mathematical point of view. However we should also consider

how the obtained results correspond to real experiences with currency crisis. In the remaining text we focus in detail on the results obtained for each country separately with reference to Appendix B.

Czech Republic

The Czech Republic faced a speculative attack on the Czech currency at the beginning of the year 1997, the national bank decided to defend the currency. However, it soon became apparent that the foreign exchange interventions are not successful and in May of the same year intermediate exchange rate regime was replaced by managed float. This change was accompanied by sharp depreciation which explains the unusually high value of exchange market pressure. Both methods identified abnormal fluctuation of exchange market pressure in 1998 and at the beginning of 1999. In this time interval the Czech crown tented to depreciate, which could have been probably associated with the fact that the national bank maintained overvalued exchange rate parity in the preceding intermediate regime. One of the highest exchange market pressure appears at the beginning of 2009. Both methods correctly identified the global financial crises which had spread to the majority of economies in the world. Unlike the stochastic approach, the deterministic one identified some evidence of forthcoming crisis already during 2008. Between January 2010 and December 2012 there occur few periods with high exchange market pressure (deterministic model identified five and stochastic model three). It seems (referring to Figure 5.1) that these observations are results of marked fluctuations of exchange rate and any positive deflection of exchange market pressure is compensated by negative in the following periods. Therefore any of these periods should not be judged as currency crises.

Hungary

Hungary is a country with highest number of currency crisis periods identified via the stochastic approach. We suppose that such a high number is correlated with relatively unstable system of exchange rate regime. At the beginning of transformation reforms, the Hungarian National Bank adopted adjustable peg, more flexible regime than in the rest of the eastern bloc countries starting the transition reforms towards market economies. Five years later this regime was substituted by crawling band, which changed either the fluctuation margins or currency basket several times during its existence. Subsequently, the regime moved to target zone in September 2001 seeing prospect of entering the European Monetary Union. However steadily worsening inflation views forced the monetary authorities to abandon the target zone and declare free exchange rate floating. Significant extreme of exchange market pressure occurs in February of 1995, which is probably related to the forthcoming change of exchange rate regime from adjustable peg to crawling band the in successive month. Although the stochastic approach identified several currency crisis occurrences between 1995 and 2002,

these changes of exchange market pressure were nowise severe and the whole period can be viewed as serene and stable. Even the change of the regime to target zone did not have any impact on stability of Hungarian forint. In 2003 the national bank worried about negative effect an overvalued forint would have at macroeconomic level, especially inflation, and decided to devaluate to higher central parity. Thus we observe excessive value of exchange market pressure at the beginning of 2003. Both model again identify the global financial crises and its effects on the exchange rate markets at the end of 2008 and early 2009. Taking into account the surveyed sample of eastern countries, the crisis had the most numbing impact on the domestic currency, for instance, the Hungarian forint depreciated by 19.52% in January of 2009 with respect to December 2008 where as for the remaining countries we cannot observe such a jump in the exchange rate parity within one month. Note that according to Hungarian exchange market pressure index the currency crisis periods identified around 2009 alter with sharp appreciation pressures. This is a unique phenomenon compared to the rest of countries. However that time the Hungarian National Bank increased markedly supply of foreign exchange reserves (see Figure 5.2) which has direct impact on the exchange market pressure index. Development of exchange market pressure between January 2010 and December 2012 is similar as in the case of the Czech Republic, i. e., few periods with high exchange market pressure were identified (in this case, the stochastic model found seven significant swings whereas the deterministic model only five). These results can be anew explained by fierce fluctuations of exchange rate and alternating of positive and negative values of exchange market pressure (see Figure 5.1).

Poland

It is worthwhile to notice that the number of currency crises periods differs markedly with identification methodology used. Whereas there are 14 periods with abnormally high value of exchange market pressure according to the deterministic approach, the stochastic one identified only 6. Moreover, as it will be discussed later, the majority of exceedances is an implication of the global financial crisis flooding. Poland can be characterized by relatively moderate fluctuation of the exchange market pressure index. We suppose that this is probably caused by very flexible exchange rate regime, the monetary authority adopted crawling peg system at the beginning of the transition reform and continued with a crawling corridor with gradually widening fluctuation margins. Thus we can conclude that 14 currency crisis periods identified employing the deterministic approach is an overestimated, since there is no evidence that Poland struggled to defend any exchange rate regime or was exposed to any speculative attacks. In Figure 5.7, we observe one significant excess at the beginning 2005. However, this could be hardly explained by any worsening situation of domestic macroeconomic situation or a speculative attack on the currency. Poland even did not change exchange rate regime that time, their currency has been floating freely

since April 2000. Presence of this isolated observation is caused by the overall development of the exchange market pressure in the preceding year, in which we find predominantly negative values with decreasing trend. As Figure 5.1 suggests, this could be a result of prolonged appreciation of Polish zloty. Therefore any slightest depreciation of the currency causes excess in the series of the index. Frequent occurrence of currency crisis period in the second half of the year 2008 is a sign of the global financial crisis. The exchange market pressure takes the highest values which, in contrast with the Czech Republic and Hungary, recur in several consecutive periods. Although the maximal percentage depreciation effect between two successive periods equals to 14.91%, whereas in the case of Hungary it is 19.52%, the overall depreciation of the currency due to the financial crisis was the most significant. Taking into account exchange rates in July 2008 and January 2009 Polish zloty depreciated by 56.63%, whereas Hungarian forint by 44.13% and Czech crown by only 31.64%. Development of exchange market pressure after the global financial crisis is comparable with previous cases. Exchange rate is extremely changeable, which causes dense fluctuations of the index.

Slovakia

Taking into account the set of explored countries, Slovakia experienced the smoothest development of the exchange market pressure. The maximum value of exchange market pressure barely exceeded the threshold of 0.1 and, except for a single observation in 1994, values fall within a very narrow corridor. Therefore we consider 9 currency crisis periods identified by the deterministic model as a highly incorrect result and question the accuracy of this approach. On contrary, the stochastic model declares that there were two currency crisis periods between January 1993 and December 2008, which seems to be more reasonable finding. Nevertheless, the result is contentious regarding the mathematical procedure applied. As we have already argued, any sample consisting of two observations would not probably fail the test of exponentiality. First years of individual monetary and exchange rate regimes adopted in Slovakia are very similar as in the Czech Republic. After division of Czechoslovakia, Slovakia continued with exchange rate targeting. Before declaring managed floating regime in October 1998, the monetary authorities adopted the intermediate exchange rate regime in the form of the corridor with rather loose fluctuation margins. Unlike the Czech Republic, Slovakia did not experience any speculative attack on domestic currency which would have forced the central bank to change the central parity or widen the fluctuation corridor. We cannot assess impact of the global financial crisis on the Slovakian crown since the period of our interest ends with joining the European Monetary Union in January 2009. Slovakia becomes monetary nonautonomous economy and further evaluation of exchange market pressure formula is distorted (the bank has no authorization to execute monetary policy in order to influence the common currency and accumulated foreign exchange reserves remain the property of the national bank and create a part of investment portfolio).

6. Conclusion

In this thesis, we examined the determinants of the market movements in exchange rates by focusing on the exchange market pressure index, which measures the extent of exchange rate developments in terms of actual depreciations while controlling for policy actions brought about by changes in international reserves and interest rates. We focused on the most relevant approaches to construction of the index together with a critical discussion on their practical application. We presented model dependent approach which utilizes monetary theory of exchange rate determination as well as models that are constructed independently of any particular model. Although there exists a rich literature focusing on comparison of model dependent and model independent approaches, there is no strong evidence that one of the methods preforms better than the other. Taking into account difficulties concerning estimation of structural model of model dependent approach, we adopted a very simple model independent approach inspired by Kaminsky, Lizondo, and Reinhart (1998). We assumed that domestic monetary policies of considered countries are independent of the demand and supply conditions for the domestic currency in the international foreign exchange market, and thus autonomous changes in domestic credit are exogenous. Consequently, we evaluated the speculative pressure via two explanatory variables, the percentage change in the domestic currency cost of one unit of foreign currency and the change in official foreign exchange reserves. Following the ideas of Kaminsky, Lizondo, and Reinhart (1998), weighting of model variables reflects different manners in the volatilities of relative change of the exchange rate and reserves in such a way that their effects on exchange market pressure are equalized. For simplicity we assumed that all parameters are time-invariant. Our aim was to utilize exchange market pressure index in order to identify currency crisis periods. Large values of the index are generally signs of forthcoming currency crisis. The majority of papers focusing on currency crisis identification uses very simple deterministic decision rule. However, since the financial series are very often characterized by heavy-tailed distributions, we prefer to employ extreme value theory in order to identify extreme values of exchange market pressure. Namely, we adopted very early methodology constructed by Hill (1975).

Despite a great popularity of exchange market pressure there is a very limited number of studies focused on central European countries founded after disintegration of the Soviet Union. Our analysis focused on four countries, the Czech Republic, Hungary, Poland and Slovakia. In the first step, we estimated exchange market pressure over the period of 20 years (January 1993 - December 2012), or 16 years (January 1993 - December 2008) in the case of Slovakia. Consequently, we judged whether these states faced to excessive exchange market pressure that could pose a threat to fulfillment of the exchange rate stability criterion. Both approaches applied, the deterministic as well as the stochastic, identified

several currency crisis periods for each country. Detailed analysis showed that the majority of marked periods were linked to either signs of currency crisis or crucial monetary policy decisions with an impact on exchange rate markets. For instance, we recognized the speculative attack on the Czech crown in 1997, which forced the monetary authority to leave the intermediate exchange rate regime and switched to the managed float. On contrary, the excesses of Hungarian exchange market pressure can be attributed to highly changeable unstable system of exchange rate regime. We found that the global financial crisis broken out in 2008 in the United States influenced exchange rate markets in considered four central European economies. Both models identified several extreme excesses of exchange market pressure at the end of the year 2008 or at the beginning of 2009. Comparing to other crisis occurred in the last decades, the crisis of 2008 did not have any serious impact on the domestic currencies of these countries, probably the worst situation experienced Poland, in which the currency depreciated more significantly in several consecutive periods and the overall depreciation attributed to the financial crisis reached the highest value. Plentiful occurrence of currency crisis periods between the beginning of 2010 and the end of 2012 in the Czech Republic, Hungary and Poland can be attributed to frequent fluctuations of exchange rate. We can conclude that the global financial crisis created relatively unstable environment at exchange rate markets of small open economies with own freely floating currencies. Although some of the periods were marked as currency crisis, the economies did not experience any dramatic depreciation and speculative attacks or any other typical features of currency crisis.

On the selected sample of countries we have proved that the stochastic approach performs better than the deterministic. Generally, the deterministic model overestimates the number of currency crisis periods for countries that have rather stable development of the exchange market pressure index. As an example we state Poland and Slovakia. Conversely, for those countries that are characterized by unstable, frequently changing, exchange rate regime, the method underestimates the number of periods in which the economy tends to be threatened by currency crisis, as we observed in the case of Hungary. In other words, the stochastic approach, unlike the deterministic one, is highly correlated with stability of exchange rate regime, which makes the method more reliable in identifying the currency crisis periods. As we have seen in the computational experiment, the isolated currency crisis observation of Polish zloty in February 2005 cannot be explained by any speculative attack, any worsening economic situation or by a change of the exchange rate arrangement. Finally, if the sequence of exchange market pressure is relatively stable, as it was true for the case of Slovakia, the stochastic approach tends to identify at least one or two currency crisis period. This happens due to mathematical determination of selecting the optimal tail fraction. Thus, we emphasize that the excesses of exchange market pressure identified by suggested stochastic approach have to be assess with respect to neighbouring observations and overall development of the series examined.

A. Fréchet family and the tail index estimator

To study the Fréchet family in more detail, we need the following definitions.

Definition 10. *If there exists a sequence of norming constants such that the asymptotic distribution of the standardized maxima is of Fréchet (or Gumbel, or Weibull) type with shape parameter ξ, we will say that F is in the maximum domain of attraction of the Fréchet (Gumbel, or Weibull, respectively) distribution H_ξ, in symbols $F \in MDA(H_\xi)$.*

Definition 11. *A positive, Lebesgue-measurable function L on $(0, \infty)$ is slowly varying at infinity if*

$$\lim_{x \to \infty} \frac{L(tx)}{L(x)} = 1, \qquad \forall t > 0. \tag{A.1}$$

One can prove (see Embrechts, Klüppelberg, and Mikosch (1997)) the following result.

Theorem 12. *F is in the maximum domain of attraction of a Fréchet distribution with shape parameter ξ if and only if*

$$\bar{F}(x) = 1 - F(x) = x^{-1/\xi} L(x) = x^{-\alpha} L(x), \qquad x > 0, \tag{A.2}$$

where L is a slowly varying function.

Let $X_1, X_2, \ldots$ be a sequence of independent random variables with common distribution function F and denote an arbitrary term in the X_i sequence by X Further let us use the notation $e(u)$ for the conditional mean of $X - u$ conditional on $X > u$, i.e., $e(u) = \mathbb{E}(X - u | X > u)$. Then we have

$$
\begin{aligned}
e^*(\ln u) &\equiv \mathbb{E}(\ln X - \ln u \,|\, \ln X > \ln u) \\
&= \mathbb{E}(\ln X - \ln u \,|\, X > u) \\
&= \frac{1}{\bar{F}(u)} \int_u^\infty (\ln x - \ln u)\, \mathrm{d}F(x)
\end{aligned}
$$

The integral on the right hand side can be computed as follows:

$$
\begin{aligned}
\int_u^v (\ln x - \ln u)\, \mathrm{d}F(x) &\overset{\text{per partes}}{=} (\ln x - \ln u)\, F(x)\big|_{x=u}^v - \int_u^v \frac{1}{x} F(x)\mathrm{d}x \\
&= (\ln v - \ln u)(F(v) - 1) + \int_u^v \frac{1}{x}(1 - F(x))\, \mathrm{d}x \\
&= (\ln v - \ln u) \int_v^\infty \mathrm{d}F(x) + \int_u^v \frac{1}{x}(1 - F(x))\, \mathrm{d}x
\end{aligned}
$$

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$$\leq \underbrace{\int_v^\infty (\ln x - \ln u)\, \mathrm{d}F(x)}_{\overset{v\to\infty}{\longrightarrow} 0} + \underbrace{\int_u^v \frac{1}{x}(1 - F(x))\, \mathrm{d}x}_{\overset{v\to\infty}{\longrightarrow} \int_u^\infty \frac{1}{x}(1-F(x))\mathrm{d}x}.$$

Applying Formula A.2 for Fréchet type of distribution function we arrive to the following formula:

$$e^*(\ln u) = \frac{1}{\bar{F}(u)} \int_u^\infty \frac{\bar{F}(x)}{x}\mathrm{d}x = \frac{1}{\bar{F}(u)} \int_u^\infty L(x)x^{-(\alpha+1)}\mathrm{d}x. \qquad (\text{A.3})$$

The following result of Karamata is often applicable (for detailed discussion see Mikosch (1999)). It essentially says that integrals of regularly varying functions are again regularly varying or more precisely one can take the slowly varying function out of the integral.

Theorem 13. *(Karamata's theorem) Let L be slowly varying and locally bounded in $[x_0, \infty)$ for some $x_0 \geq 0$. Then*

- *for $\alpha > -1$*

$$\int_{x_0}^x t^\alpha L(t)\, dt \sim -\frac{1}{\alpha+1}x^{\alpha+1}L(x), \qquad x \longrightarrow \infty, \qquad (\text{A.4})$$

- *for $\alpha < -1$*

$$\int_x^\infty t^\alpha L(t)\, dt \sim -\frac{1}{\alpha+1}x^{\alpha+1}L(x), \qquad x \longrightarrow \infty. \qquad (\text{A.5})$$

Considering distribution function of Frechet, parameter α satisfies $\alpha > 0$ and thus applying the Approximation A.5 to the result obtained in Formula A.3 we get

$$e^*(\ln u) \sim \frac{L(u)u^{-\alpha}}{\alpha\bar{F}(u)} = \frac{1}{\alpha}, \qquad u \longrightarrow \infty. \qquad (\text{A.6})$$

Consider a sequence $x_1, \ldots, x_n$ as realizations of independent and identically distributed random variables $X_1, \ldots, X_n$. Let $x_{1:n}, \ldots, x_{n:n}$ represent the data in decreasing order, i.e., $x_{1:n} \geq \ldots \geq \ldots, x_{n:n}$. Then for given $k = 1, \ldots, n$ the empirical estimate of $e^*(\ln x_{k:n})$ is given as

$$e^*(\ln x_{k:n}) = \frac{1}{k}\sum_{j=1}^k \ln x_{j:n} - \ln x_{k:n},$$

thus it follows from Formula A.6 that the estimate of the tail index for given k has the following form

$$\hat{\alpha}_{k,n}^H = \left(\frac{1}{k}\sum_{j=1}^k \ln x_{j:n} - \ln x_{k:n}\right)^{-1}. \qquad (\text{A.7})$$

It remains to derive the estimate of distribution function F, for convenience we make inference for $\bar{F}$. For u large enough we assume that $\bar{F}$ has the approximate form $\bar{F}(x) \doteq Cx^{-\alpha}$ for $x \geq u$, where C a positive constant such that $C = u^{\alpha}\bar{F}(u)$ (definition of C follows from the previous equation by substituing threshold u). Now assume $k = 1, \ldots, n$ to be fixed and set the threshold equal to $x_{k:n}$, then

$$\widehat{\bar{F}(x)} = \frac{k}{n}\left(\frac{x}{x_{k:n}}\right)^{-\hat{\alpha}^H_{k,n}}, \qquad \text{for } x \geq x_{k:n}. \tag{A.8}$$

B. Overview of countries exchange rate regimes

Former transition economies, now members of the European Union, used different exchange rate regimes and monetary policy frameworks in the transition process, on the road to the European Union membership. Most countries at the beginning of the transition process used an exchange rate as a nominal anchor policy. After this initial stabilization phase, there were three main options for further regime. The first group of coutries (comprising Estonia, Lithuania and Latvia) chose to keep rigid exchange rate in form of either currency board accompanied by exchange rate targeting monetary regime or a conventional fixed peg. The second group of countries (including Slovenia, Bulgaria and Romania) followed no specific way, staying on the rigid exchange rate form or performing more flexible regimes with different nominal anchors. The last group of former transition economies that changed monetary and exchange rate regimes during the transition process consists of Poland, the Czech Republic, Slovakia and Hungary. All these countries first used exchange rate as a nominal anchor and then switched to a more flexible (some kind of intermediate form) exchange rate regime. Finally, they accepted free or managed floating exchange rate regimes and explicit or implicit inflation targeting framework. Slovakia is now member of the European Monetary Union, while Poland, the Czech Republic and Hungary still do not either participate in European Exchange Rate Mechanism II.

In the following text, we shortly review the experience of the Czech Republic, Hungary, Poland and Slovakia, we focus on main changes concerning the choices of monetary and exchange rate regimes. The most relevant sources for the summary are papers by Josifidis, Allegret, and Beker Pucar (2009) and Zoican (2009). The following overview enables us to relate currency crises periods identified in the latter calculation to crutial changes in monetary and exchange rate regimes. Thus we could assess if any of the currency crisis resulted in a change of any of the regimes or conversely if any change of monetary or exchange rate policy caused a currency crises.

Czech Republic

Czechoslovakia started with transition reforms in January 1990, choosing a fixed exchange rate with narrow fluctuation margins $\pm 0.5\%$ regarding the basket peg (including the currencies of key trading partners, i. e., Germany, the United States, Austria, Switzerland and the United Kingdom). In January 1993, Czechoslovakia was divided into two separate countries, the Czech Republic and Slovakia, and monetary union between them disappeared. In May 1993, monetary authorities of the Czech Republic decided to restructure the currency basket

and confined it to the German mark with 65% ratio and the American dollar with 35% ratio. There were no crucial changes until February 1996 when the Czech Republic switched its exchange rate regime from conventional fixed to intermediate regime in the form of the corridor with ±7.5% fluctuation margins. At the same time, exchange rate targeting was abandoned and accepted the combination between exchange rate and monetary targeting (M2 monetary aggregate). However, in May 1997, under a speculative attacks, the Czech crown depreciated, along with other crisis indicators, and monetary authorities were forced to leave intermediate exchange rate regime and accept managed floating. A new monetary strategy of inflation targeting, compatible with more flexible exchange rate regime, was officially accepted in December 1997.

On the base of described changes of exchange rate regimes in the Czech Republic, key subperiods are

- January 1993 - February 1996: conventional fixed parity with fluctuation margins ±0.5%,

- February 1996 - December 1997: intermediate exchange rate regime in the form of a corridor of ±7.5%,

- May 1997 - December 2012, managed floating exchange rate regime.

Hungary

Taking into account the eastern bloc countries, albeit probably Poland, Hungary has experienced the largest number of different exchange rate regimes between 1990 and 2008. At the beginning of the transition reforms, due to fears that inflationary pressures in Hungary might rapidly lead to an overvalued forint, the Hungarian National Bank decided to adopt a slightly more flexible regime, i.e., an adjustable peg relative to a basket of currencies, weighted by their importance in Hungarian trade. This arrangement was then modified in 1994, when the only currencies in the basket remained the American dollar (50% weight) while the rest of the basket was represented by European Currency Unit (the euro's predecessor) and the German mark. By 1995, Hungarian monetary authorities felt more confident in their abilities to handle the mechanisms and therefore, a new, more flexible crawling band (with fluctuation margins of ±2.5%) replaced the adjustable peg. Such a regime was regarded as a good compromise between the need for credibility of the central bank and competitiveness of the forint. One of the more subtle changes in the exchange rate regime was the very components of the currency basket: European Currency Unit, followed by German mark and the euro (after 1999) accounted for 70% of the basket, while the US Dollar weight dropped from 50% before 1995 to only 30%. Since January 2000, euro was the only currency the forint was crawling against. In May 2001, the National Hungarian Bank widened the band to ±15% which resulted in a strong appreciation of the

Hungarian forint in the following period showing that the currency was kept artificially undervalued by the previous band or simply a wave of optimism in response to this action of the national bank. In September 2001, after considering that there is no further need to pursue a constant-paced devaluation of the forint against Euro, encouraged probably by the events in May the same year, when the forint proved itself consistently undervalued, the crawling system was abandoned. The exchange rate regime moved to target zone, a system strikingly similar to the European Exchange Rate Machanism II, i. e., the value of the forint was allowed to move around a central parity against euro within a ±15% band. Later, in 2003, the national bank pondered the negative effect an overvalued forint would have at macroeconomic level and decided to devalue the forint to higher central parity. Although maintanance of a system similar to European Exchange Rate Machanism II was widely supporetd, the deteriorating inflation outlook in Hungary brought the need for a stronger forint than the band would have allowed. Not desiring to alter the interest rate and increase it even more, the Hungarian National Bank chose to abandon the target zone against Euro and let the forint float freely.

According to presented exchange rate regime changes in Hungary since the beginning of the transition, we distinguish the following subperiods

- Janury 1990 - March 1995: adjustable peg,

- March 1995 – September 2001: crawling band regime with widening fluctuation margins (with varying currency basket),

- September 2001 - February 2008: target zone,

- February 2008 - December 2012: free exchange rate floating.

Poland

Transition reforms in Poland started in January 1990 with the adoption of fixed exchange rate and then a monetary strategy based on exchange rate targeting. This monetary regime was one of the main foundations of the economic strategy in the phase of macroeconomic stabilization. The Polish currency, the zloty, was initially tied to the American dollar. In the aftermath of the May 1991 devaluation, the exchange rate regime moved from dollar pegging to a basket. In October 1991, Poland used more flexible exchange rate form (compared to the previous conventional fixed parity), concretely forward looking crawling basket peg. Such a regime was used since October 1991 until May 1995 while the rate of crawl was decreased from 1.8% to 1.2%. From May 1995 to April 2000, Poland adopted a crawling corridor or target zone with fluctuation margins of ±7%. This exchange rate arrangement constitutes a new step toward higher exchange rate flexibility. After this date, Poland finally accepted a flexible exchange rate

regime. However, in the period of the crawling corridor, very frequent changes of the corridor's characteristics existed, above all, gradual widening of fluctuation margins (in February 1998 ±10%, in October 1998 ±12.5%, and in March 1999 ±15%) and decreasing of monthly crawl rate (from 1.2% in February 1995 to 0.3% in March 1999). Changes of monetary and exchange rate policy have been conducted gradually from exchange rate to inflation targeting and from conventional fixed parity to a free floating exchange rate regime. Gradual transition toward higher exchange rate flexibility has been shown as a correct strategy concerning achieved and maintained macroeconomic stability. Macroeconomic stability was primarily achieved due to exchange rate as a nominal anchor policy, but it has been kept due to changed monetary strategy with more discretion and autonomy.

Considering the previous description, in the case of Poland we can identify three different phases of the exchange rate arrangeents

- January 1990 – May 1995: conventional fixed parity and crawling peg with decreasing rate of crawl,

- May 1995 – April 2000: crawling corridor regime with widening fluctuation margins and decreasing rate of crawl,

- April 2000 - December 2012: free exchange rate floating.

Slovakia

Empirical research related to individual monetary and exchange rate regimes starts with January 1993, having in mind already mentioned division of the monetary union between the Czech Republic and Slovakia. Slovakia, similarly as the Czech Republic, continued after division with exchange rate targeting in order to achieve macroeconomic stability. The exchange rate was used as a nominal anchor for four years. Changes were related only to the basket restructuring in January 1994 (60% German mark and the remaining 40% American dollar), and the widening of fluctuation margins to 1.5%. After the period of exchange rate targeting, a new intermediate exchange rate regime in the form of the corridor with fluctuation margins ±7% was adopted in January 1997. The exchange rate regime was changed into managed floating in October 1998. In contrast to Poland and the Czech Republic, Slovakia is a member of the European Monetary Union and previously participated in European Exchange Rate Mechanism II. Hence, after managed floating, the exchange rate regime was again moved toward intermediate option of the target zone with ±15% fluctuation margins in November 2005. The last change assumed monetary non-autonomy and rigid exchange rate regime with joining the Eurepean Monetary Union in January 2009.

According to mentioned exchange rate regime changes in Slovakia since the beginning of the transition, the following subperiods have been identified

- January 1993 - January 1997: conventional fixed parity,

- January 1997 - October 1998: intermediate exchange rate regime in the form of the corridor,

- October 1998 - November 2005: managed floating regime,

- November 2005 - January 2009: intermediate regime of the corridor or target zone (European Exchange Rate Mechanism II),

- January 2009 - December 2012: and rigid exchange rate regime (membership in the Eurepean Monetary Union).

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