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Financial Stress Spillover and Financial Linkages between the Euro Area and the Czech Republic*

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Abstract

This article analyzes the transmission of financial systemic stress from the euro area to the Czech Republic. We employ a recently developed composite indicator of systemic stress (CISS), which has a unique construction reflecting the correlations between markets and so captures the systemic stress of the financial system. The results from time-varying regression with stochastic volatility estimated using Bayesian inference indicate that the degree of transmission depends significantly on the level of stress, i.e., the intensity of the transmission mechanism itself is given by the magnitude of the shock. Second, the analysis reveals a more complex structure of financial stress linkages between markets on both the domestic and the international level. Finally, the results also support the current findings that the nature of stress is important for the transmission and that the sovereign debt crisis has so far had a limited impact on Czech financial markets.

1. Introduction

The global financial crisis of 2007–2008 attracted a large body of research into the topic of how and to what extent systemic shocks, or more generally financial stress, are transmitted between countries. Interest in the topic has been intensified by the more recent European sovereign debt crisis. The literature so far points to a major difference between the two events. Whereas the first crisis was global and systemic, the current debt crisis has not spilled over worldwide so dramatically and has not affected the global financial system so severely.

This article analyzes the transmission of financial stress from the euro area to the Czech Republic. The Czech Republic is a financially open country with strong trade and financial linkages with the euro area,[1] so any shock stemming from the euro area is transmitted to the domestic economy and an increase in the risk aversion of global investors leads to withdrawal of funds from the country.

Our article extends the existing literature in several ways. First, it constructs an indicator of (financial) systemic stress for the Czech Republic using the method-

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[1] Our choice to study the direct link between the euro area and the Czech Republic was driven by findings in the literature on the main transmission channels of the financial stress from advanced to emerging markets, i.e., bank lending (financial) and trade linkages (see IMF, 2009). The banking sectors are connected mainly by ownership structures, as subsidiaries of EU banks account for more than 80% of the total assets of the Czech banking sector. The potential for contagion due to cross-border financial linkages is well described in Geršl (2007).

ology of Hollo et al. (2012), which can be defined as the materialization of systemic risk at a given time. In this sense it measures "the contemporaneous instability of the whole financial system" (Hollo et al., 2012), so it ultimately captures only one dimension of systemic risk. It is constructed on a weekly basis, allowing for regular and timely monitoring. This indicator measures the level of instability in the financial system and incorporates all information in a given period into one single number, which allows for easy interpretation.

Second, the construction of the index enables us to study the transmission of financial stress from the euro area to the domestic economy. In contrast to previous studies, we focus on the risk within the whole financial system, i.e., our focus is not limited to the transmission of volatility. By definition, the important aspect of our indicator is contagion,[2] which can occur across borders and is relevant to countries with a high degree of financial openness and integration such as the Czech Republic. So, indirectly, this approach offers an insight into financial integration and the strength of financial linkages between countries. Our indicators of financial stress cover all markets and allow us to study spillover in a comprehensive way. We do not have to assume any direct link between specific markets (e.g., between the euro area and the Czech stock market). Instead, employing one indicator and its sub-indices enables us to find the links. Moreover, we use an estimation technique which is easy to follow and interpret.

Third, the European sovereign debt crisis has a different nature and its impact on emerging countries has been found to be lower compared to the previous financial crisis. Our framework sheds some light on the reasons for the different behavior of the markets in 2011. We do not aim, for the time being, to identify periods of stress in the Czech financial markets or to evaluate the impact of the crisis on the domestic economy. Instead, our main aim is to show that the financial stress is a global phenomenon far stronger than we currently believe.

The article is structured as follows. First, we will introduce the concept of financial stress and review the ways of measuring it. We will explain the linkages between markets and the channels of propagation of stress from one economy to another. Next, we will construct our indicator of stress for both the eurozone and the Czech Republic. Finally, we will examine how financial stress has been transmitted from the eurozone to the Czech Republic. We will employ two time-varying measures, which allow us to track how the transmission and thus the vulnerability of the Czech financial system have evolved over time.

2. Financial Stress, Systemic Risk, and Contagion

Periods of elevated financial stress are characterized by interruption of the normal functioning of financial markets. Such breakdowns are largest at times of crisis. According to Illing and Liu (2006) and Grimaldi (2010), the level of financial stress reflects the interacting dimension of the shock and the vulnerability of markets. If the markets are vulnerable, there is a higher probability that they will be in stress if a shock occurs.

Financial stress has many symptoms, which can appear individually or together (Hakkio and Keeton, 2009):

[2] There is an ongoing discussion on the definition of contagion; we mean mainly the spread of financial distress between countries. For further discussion see Kolb (2011, p. 4).

- *Higher uncertainty about the fundamental price of one asset and/or group of assets*: the uncertainty that arises when investors are unable to match economic states with probabilities causes investors to overreact when new information arrives, leading to higher volatility of market prices.
- *Higher uncertainty about the behavior of other investors*: if uncertainty dominates, the behavior of other investors and/or of the dominant investor becomes relevant (herd effect).
- *Information asymmetry*: at times of financial stress there is a gap in the distribution of information between buyers/sellers or debtors/creditors.
- *Flight to quality*: a lower willingness to hold risky assets causes a rise in the required returns on these assets and safe assets are preferred.
- *Flight to liquidity*: financial stress also leads to higher demand for liquid assets, because higher volatility increases the probability that investors will have to liquidate their positions. There may also be a change in the perceived liquidity of assets.

There have been several attempts in the literature to find variables that capture all signs of financial stress in the best possible way and to aggregate them into one simple indicator. This approach does not have a strong theoretical background, but it has proved useful in understanding financial crises, which have differing natures and sources (banking sector, public debt), but always have a substantial impact on the real economy. This impact is empirically analyzed, for example, by Cardarelli, Elekdag, and Lall (2009), who show that financial crises accompanied by banking sector stress are followed by larger and deeper recessions than crises purely in debt or currency markets.

Understanding which markets are hit most severely by turbulence is a key element in identifying the impacts of crises. Financial stress indicators provide us with such information in real time and show the level of contagion between markets. In this sense, they can tell us a lot about systemic risk. There is no simple definition of systemic risk, but two elements are usually stressed in the literature—contagion and a strong effect on the real economy. As explained in ECB (2009), a systemic event affects "a number of systemically important intermediaries or markets (including potentially related infrastructures)". An event is considered strong if the normal functioning of the markets is interrupted and the impact on trade and economic situation is substantial.

Several financial stress indicators have been introduced which use data from the financial markets only.[3] The very first such study, by Illing and Liu (2006), showed that this approach is capable of identifying the majority of stressful events (as perceived by experts). Illing and Liu's (2006) financial stress indicator for Canada was chosen for the analysis of various different types of crises (banking, currency, public debt, and stock market crises). A similar approach, applied to 17 advanced economies, was taken by Cardarelli, Elekdag, and Lall (2009).

Hakkio and Keeton (2009) employ a different technique for selecting variables based on the signs of stress as defined above. Their Kansas City Financial

[3] There is also a large stream of literature developing crisis early warning systems. These studies use macroeconomic data and indicators of banking sector stability. An example for the Czech Republic, among other countries, is the recent study by Babecký et al. (2011).

Stress Index for the United States is still actively used in the Federal Reserve Bank of Kansas City. A similar indicator is published by the Federal Reserve Bank of St. Louis. A number of private companies (Bloomberg, Deutsche Bank, etc.) construct financial stress indicators for the USA and other countries.

The studies also differ in terms of aggregation methods. The standard approaches are the variance-equal weight method, i.e., standardizing variables (e.g. Cardarelli et al., 2009; Yiu, Ho, and Jin, 2010; Sandahl et al., 2011), and factor analysis using principal components (Illing and Liu, 2006; Hakkio and Keeton; 2009). The latter has the advantage that the individual weight in the index reflects its historical importance with regard to fluctuations in the financial system. Other studies employ logit models to construct a stress index that shows the probability of stress (Nelson and Perli, 2007; Grimaldi, 2010).

Recently, the focus has moved to the construction of a financial stress indicator able to capture the systemic nature of stress. As we have pointed out, contagion is an important element of systemic risk, so this index should reflect situations where stress materializes in several markets simultaneously.[4] A recent contribution by Brave and Butters (2010) develops a state-space representation of the level of systemic stress. This approach takes into consideration the cross-correlations of a large number of financial variables (100 indicators) and the past development of the index to set the weights for each sub-index. Standard portfolio theory is used by Hollo et al. (2012) to aggregate sub-indices, again reflecting their cross-correlation structure. A simple version of the previous work has also been implemented for 28 advanced and emerging countries (Lo Duca and Peltonen, 2011). Oet et al. (2011) present a financial stress indicator where the dynamic sector weighting should reflect its relative importance and capture the systemic nature of the stress.

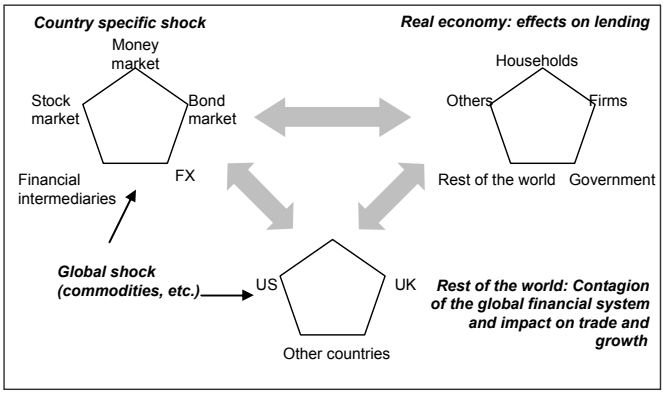
In this paper, we follow this approach to study the transmission of financial systemic stress between regions. *Figure 1* shows a schematic representation of the linkages between sectors and countries. If a country faces a shock to its financial system (such as a failure of a bank), that shock has a direct impact on the level of stress in other markets, affecting lending conditions in the economy.[5] If the risk becomes systemic, the functioning of the markets is limited while contagion of the global financial system is going on. Such linkages appeared as a result of financial integration and proved highly relevant during the global financial crisis in 2008––2009.

In fact, findings from the literature based on financial market data provide supportive evidence that the crisis was of a systemic nature. The transmission of the financial stress from advanced to emerging markets was directly studied by IMF (2009). The analysis (based on monthly data) consisted of separating a common time-varying component for the emerging economies, which is subsequently explained by the financial stress indicator for advanced economies. Other authors have employed more sophisticated methods on higher-frequency data, still on an individual market

[4] An overview of systemic risk studies can be found, for example, in Schwaab, Koopman, and Lucas (2011).

[5] The channels for shock transmission across countries are discussed in Dornbusch, Park, and Claessens (2000) and more theoretically in Pericoli and Sbracia (2003).

Figure 1 Transmission of Financial Stress



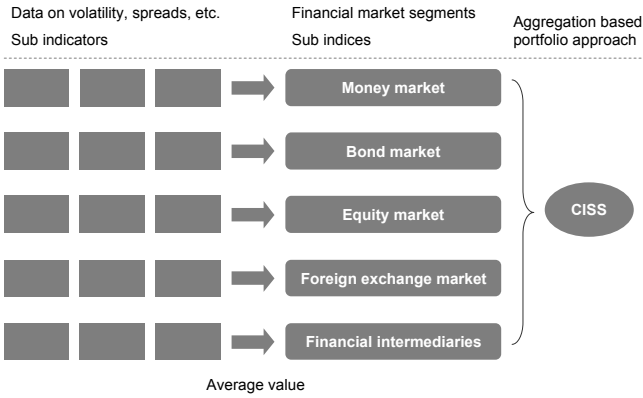
Source: Authors.

level only. Frank and Hesse (2009) studied the transmission of stress between advanced and emerging stock/bond markets using a GARCH model. Again, they found that during the peak of the last crisis the increase in global risk aversion spilled rapidly to emerging economies and investors resorted to safe and liquid assets in their home markets. A contagion effect from U.S. to Asian and Latin American stock markets during the financial crisis was identified by Yiu, Ho, and Jin (2010). They estimated the time-varying volatility correlation using an asymmetric dynamic conditional correlation model.

In recent years, volatility spillover, which is closely related to financial stress transmission, in both tranquil and more turbulent times has gained a lot of attention in the literature. A review of volatility transmission can be found in Soriano and Climent (2006). Most studies support the idea of growing linkages between markets due to globalization, but research specifically for Central and Eastern European countries is rather limited. As for the stock market, Wang and Shih (2010) find significant volatility spillover effects from the world and European region to CEE countries. Similarly, Hanousek et al. (2009, 2011) reached the same conclusion for spillover at intraday frequency, while Egert and Kočenda (2011) found no strong correlation between the euro area and the Czech stock markets prior to the crisis. Bubák, Kočenda, and Žikeš (2011) analyze the volatility transmission between Central European (CE) currencies and EUR/USD. They conclude that the regional volatility spillovers are substantial, while some volatility spillover from EUR/USD to Czech koruna is evident. Also, volatility spillovers tend to increase in periods characterized by market uncertainty. Morales (2008) finds no spillover effects between currency and stock markets in the Czech Republic, Hungary, Poland, and Slovakia.

The cross-border reaction of markets is often studied with respect to financial integration. The benefits of increased financial integration may be outweighed by the risks of contagion. A recent study by Babecky et al. (2010) showed that financial integration between the Czech Republic and the euro area has continued in recent years, with the financial crisis causing only temporary price divergence. The direct effect of the crisis on the Czech financial system and its liquidity was examined by Geršl and Komárková (2011). They found that even in countries not directly hit

Figure 2 Composition of the Financial Stress Indicator



Source: Authors.

by the crisis a negative liquidity spiral appeared, suggesting a strong impact on the financial system. So, while the effect of global developments on the Czech financial markets is straightforward and worth investigating, we leave aside the effects of macro-financial interactions, even though they are substantial (Havranek et al., 2010; Franta et al., 2011).

3. Composite Indicator of Systemic Stress (CISS)

In this section, we describe the construction of financial stress indices for the Czech Republic and the EMU using the approach of Hollo et al. (2012),[6] an overview of which is depicted in *Figure 2*. The composite indicator of systemic stress (CISS) is based on inputs from five segments of the financial system—the money market, the bond market, the stock market, financial intermediaries, and the foreign exchange market. Each of these inputs is based on two or three sub-indicators, which provide information on financial stress. The exact composition of the sub-indicators is presented in *Appendix A1*, but in general, the following types of information are used—volatilities of returns (or yields); spreads between two financial instruments; measures of potential loss (maximum cumulative loss); idiosyncratic risk of an instrument.

The indicators from the five segments are then aggregated into a unique indicator of financial stress using the portfolio approach. Therefore, the final index is not the simple mean of the five sub-indices, but correlations play an important role to reflect systemic risk. As a result, the stress index is highest when the stress on individual markets is high and the correlations between markets are high as well, i.e., when the stress on the financial markets becomes systemic.

The construction of this financial stress indicator has three unique features. The first is the transformation of simple indicators, which makes them comparable. Many previous studies use "variance-equal weighting," i.e., the indicators are first de-meaned and then divided by their standard deviation. The pitfall of this approach

[6] Another indicator based on this study is by Louzis and Vouldis (2011) for Greece. They also used data for the banking sector and compared the evolution of the indicator with expert surveys.

is its strong sensitivity to outliers and to the arrival of new information in typically small samples. Any new value shifts the mean and standard deviation of the indicator substantially, so that the whole trajectory of the stress index is altered in each period. To overcome these problems, a more robust transformation is used when constructing the CISS. It transforms the measure into quantile statistics based on sample cumulative distribution functions (CDFs)—for details, see Hollo et al. (2012). The sample relative to which a current value is compared can be chosen in two ways —recursively (the current value is compared to all the past values) or non-recursively (the current value is compared to all values in the sample). The results in the original paper show that the outcomes of these two approaches are very similar, so the first approach is used, as it is more intuitive and the arrival of new information does not alter the historical values of the index.

The second original feature of this approach is that the final aggregation captures both dimensions of systemic risk—widespread financial instability and the impact on the real economy. All five sub-indices are weighted based on their impact on the real sector of the economy. For the euro area the weights were chosen following Hollo et al. (2012): money market (15%), bond market (15%), stock market (25%), financial intermediaries (30%), and foreign exchange market (15%). The importance of the stock market for the real economy is lower in the Czech Republic,[7] while the importance of the foreign exchange market is slightly higher due to the country's openness. Therefore, the following weights were chosen: money market (15%), bond market (15%), stock market (20%), financial intermediaries (30%), and foreign exchange market (20%), reflecting the high trade openness of the Czech Republic. The results are robust to changes to the weighting.

The third innovation is the way the sub-indices are aggregated into the final stress index. This is achieved using the portfolio approach, i.e., both the values of the sub-indices and the correlations between them are exploited.

As the correlation between the sub-indices varies significantly over time, it is calculated using exponentially weighted moving averages (EWMA). More formally, let y_t be a row vector, which takes on the value of the sub-indices multiplied by their weight (as described above). Let $C_{ij,t} = \left(\rho_{ij,t}\right)_{i,j=1\ldots5}$ be the matrix of time-varying cross-correlation coefficients, where the individual correlation coefficients are calculated using EWMA:

$$\sigma_{ij,t} = \lambda\sigma_{ij,t-1} + (1-\lambda)\tilde{s}_{i,t}\tilde{s}_{j,t} \tag{2.1}$$

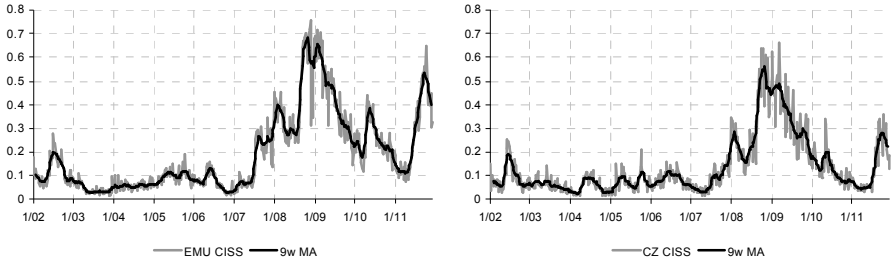
and

$$\rho_{ij,t} = \frac{\sigma_{ij,t}}{\sigma_{i,t}\sigma_{j,t}} \tag{2.2}$$

where $\tilde{s}_{i,t} = \left(s_{i,t} - 0.5\right)$ is the difference of an index from the theoretical median of 0.5.

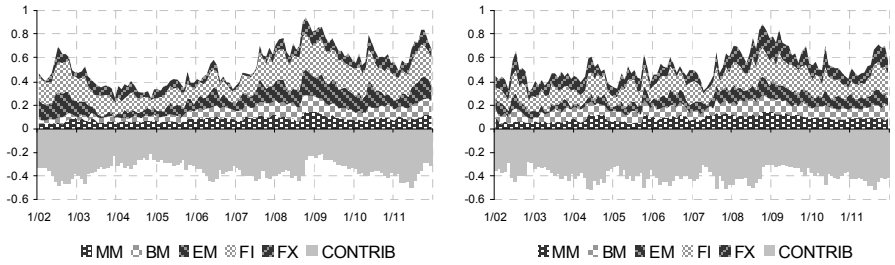
[7] There is no study evaluating the impact of different financial sectors on the Czech economy and we still do not aim to assess the extent to which our indicator is of a systemic nature (in the sense of real impacts). However, we lowered the share of the stock market due to its substantially lower importance in the Czech economy compared to that of the euro area. This is supported by the fact that the stock market capitalization of the euro area fluctuated between 38% and 86% of GDP, while the same indicator for the Czech Republic was below 42% in the period under review.

Figure 3 CISS for the Euro Area and the Czech Republic



Note: 9w MA denotes the nine-week moving average of the original time series.
Source: Authors' calculations.

Figure 4 Contributions of Individual Markets to the Overall Stress Index in the Euro Area and the Czech Republic



Note: The sum of the positive values gives an index assuming perfect correlation, while the negative contribution stems from the impact of correlation between markets.
Source: Authors' calculations.

The aggregate stress index is calculated using the formula $FSI_t = \sqrt{y_t C_t y_t'}$. We can easily observe that the final index values range between 0 and 1.

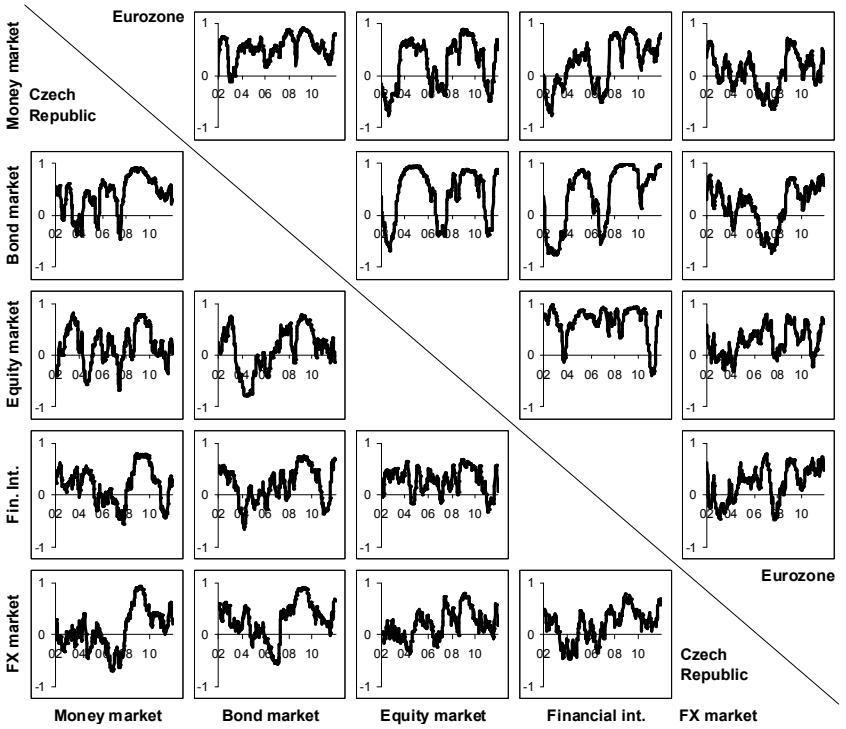
4. Evolution of the CISS for the Euro Area and the Czech Republic

Our CISS for the Czech Republic and the EMU is calculated using daily data from 1 January 1999 to 31 December 2011, but due to the transformations and final aggregation, the final index starts in January 2002 and has a weekly frequency. The data were collected from DataStream, Bloomberg, and the ECB. Both indices are presented in *Figure 3*.

Several features are apparent. The overall index of the Czech Republic follows a similar pattern as that of the euro area. Some country-specific events are also present (strong appreciation of CZK in 2002, debt crisis in euro area in 2011), while the evolution of the index in both countries in 2008–2009 supports the systemic nature of the index. The individual sub-indices are plotted in *Appendix A2*.

The underlying forces behind the CISS can be seen by decomposing it into the contributions of individual markets excluding their cross correlations. *Figure 4* (positive values) shows the contributions assuming perfect correlation, i.e., the weighted average of the five sub-indices. This weighted average will always be higher than

Figure 5 Cross Correlations between Individual Markets in the Euro Area and the Czech Republic



Source: Authors' calculations.

the CISS, as the contribution of the cross correlation is negative (the area below the zero line in the chart).

Comparing the contribution structure, it is necessary to bear in mind the different weights of the markets in the total weighted average. Overall, most of the financial stress comes from the sector of financial intermediaries, while their average contribution for CZ is somewhat lower. On the other hand, the Czech CISS has a larger contribution from the FX market.

An important element of the CISS is its ability to capture systemic events, when stress is prevailing on numerous markets at the same time. This correlation effect is time-varying, reflecting the time-varying correlations between financial market segments. It was particularly strong after the collapse of Lehman Brothers, and it was present both in the euro area and the Czech Republic (see *Figure 5*).

Even from the previous figure it is clear that some markets are more correlated in any given period than others, suggesting the presence of permanent interlinkages between financial markets. The first hint, still bearing in mind the limitation of such an approach, comes from the correlation analysis.

Table 1 shows the correlation coefficients between the sub-indices of the individual markets for the euro area and the Czech Republic and between the two

Table 1 Correlation Coefficient for Sub-Indices

EURO AREA	Bond market	Equity market	Financial intermediaries	Foreign exchange market
Money market	0.62	0.37	0.39	0.16
Bond market		0.54	0.60	0.28
Equity market			0.76	0.25
Financial intermediaries				0.34

CZ	Bond market	Equity market	Financial intermediaries	Foreign exchange market
Money market	0.38	0.39	0.28	0.16
Bond market		0.29	0.31	0.40
Equity market			0.34	0.28
Financial intermediaries				0.27

CZ/EURO AREA	Money market	Bond market	Equity market	Financial intermediaries	Foreign exchange market
Money market	0.48	0.55	0.29	0.32	0.12
Bond market	0.22	0.45	0.19	0.30	0.37
Equity market	0.40	0.58	0.61	0.53	0.19
Financial intermediaries	0.24	0.36	0.39	0.36	0.19
Foreign exchange market	0.17	0.31	0.37	0.50	0.46

Note: Whole sample included.
Source: Authors' calculations.

regions. In both regions we observe that the indicators of financial stress for bond markets, equity markets, and financial intermediaries are rather correlated, while the FX market stands apart. This may be due to higher volatility of the indicator, while the coefficients for CZ (especially vis-à-vis that bond market and financial intermediaries) are slightly higher. This supports our assumption of FX having a higher weight in the aggregation.

When studying inter-linkages between markets, it is usually assumed that the shocks are transmitted to the same market segments in different countries (i.e., between countries' stock markets or bond markets), which is rather binding. A first glimpse at *Table 1* suggests that the correlation is the highest between the same markets in different countries (the diagonal in the third table), but not in all cases. The structure seems to be more complicated. For example, the Czech stock market seems to react far more to developments in the euro area (except for the exchange rate) than to those in domestic markets. We will investigate this issue further in the next section, using more appropriate instruments.

5. Spillover of Financial Stress from the Euro Area to the Czech Republic

The literature does not offer any preferred methodology for measuring the transmission of financial stress from one region to another. For example, IMF (2009) presents an empirical model of contagion using a common time-varying component in emerging countries, which is explained by the development of financial stress in

advanced countries. The preferred framework in the literature on volatility spillover is GARCH, which is not applicable to our case either.

We employ a different approach—time-varying regression, where we estimate to what extent the current level of financial stress in the Czech Republic depends on the level of financial stress in the euro area. The time-varying nature of the covariates (i.e., the intercept and slope) is natural, since not only the size of shocks (the explanatory variable), but also the transmission mechanism (regression coefficients) changes over time, particularly at times of elevated financial stress. The results from various stability tests of the linear regression model point to several structural breaks, suggesting that a time-varying regression model is appropriate.

In addition to the time-varying nature of the covariates, we assume that the volatility of domestic shocks to the Czech financial system is time-varying and model it as a stochastic volatility process. Following Nakajima (2011), the time-varying regression with stochastic volatility is estimated using Bayesian inference.

We assume the following time-varying regression:

$$CISS\_cr_t = \alpha_t + \beta_t CISS\_emu_t + \varepsilon_t,\ \varepsilon_t \sim N\left(0, \sigma_t^2\right),\ t = 1, \ldots, n, \tag{3.1}$$

where the dependent variable is the value of the Czech CISS and the explanatory variable is the eurozone CISS level. The coefficients on the covariates are assumed to follow a random-walk process:

$$\begin{pmatrix} \alpha_{t+1} \\ \beta_{t+1} \end{pmatrix} = \begin{pmatrix} \alpha_t \\ \beta_t \end{pmatrix} + \begin{pmatrix} u_{\alpha,t} \\ u_{\beta,t} \end{pmatrix}, \begin{pmatrix} u_{\alpha,t} \\ u_{\beta,t} \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \Sigma_\alpha & 0 \\ 0 & \Sigma_\beta \end{pmatrix} \right) \tag{3.2}$$

This allows for smooth evolution of the covariates, as well as for sudden "jumps" or structural changes. Finally, the volatility of the residuals in the observation equation follows a standard stochastic volatility process:

$$\sigma_t^2 = \gamma \exp\left(h_t\right) \tag{3.3}$$

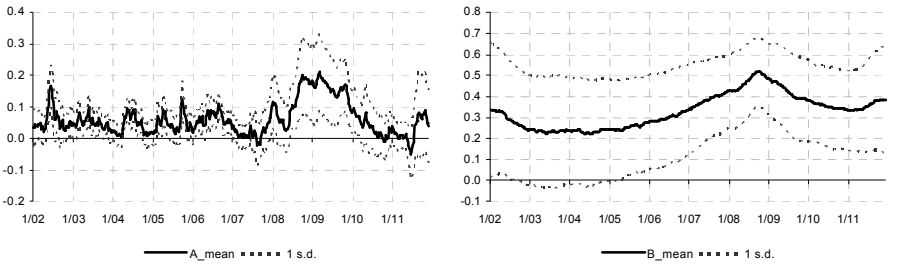
and

$$h_{t+1} = \varphi h_t + \eta_t,\ \eta_t \sim N\left(0, \sigma_\eta^2\right),\ t = 0, \ldots, n-1 \tag{3.4}$$

We assume non-informative priors on the initial values of the state variables $\left(\alpha_0, \beta_0, h_0\right)$ and all the hyperparameters $\left(\Sigma_\alpha, \Sigma_\beta, \sigma_\eta^2, \gamma, \varphi\right)$; their precise values and distributions can be found in Nakajima (2011).

The Gibbs sampler was run for 10,000 iterations and the mean and confidence bounds of the unobservable states (time-varying covariates) are depicted in *Figure 6*. During the most stressed period of 2008 and 2009, both the intercept (A_mean) and the slope (B_mean) increased substantially, indicating strong propagation of the shocks. After the stabilization in 2010 we see a substantial drop in the intercept to its level prior to the financial crisis. On the other hand, the slope, i.e., how strong the effects are, remained elevated. During the recent sovereign debt crisis it increased slightly, but it is still lower than during the peak of the financial crisis. This is in line with the literature finding that the impact of the financial turmoil in the eurozone on emerging markets has been less pronounced recently (Chudik and Fratzscher, 2012).

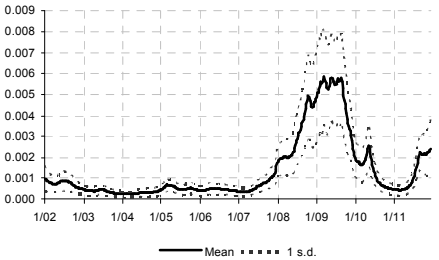
Figure 6 Time-Varying Coefficients from the Regression $CISS\_cr_t = \alpha_t + \beta_t CISS\_emu_t + \varepsilon_t$



Note: Bold line is the mean value of draws of the covariates using Gibbs sampler; the dotted lines denote 1 s.d. posterior bands .

Source: Authors' calculations.

Figure 7 Estimated Volatility of the Residuals ε_t



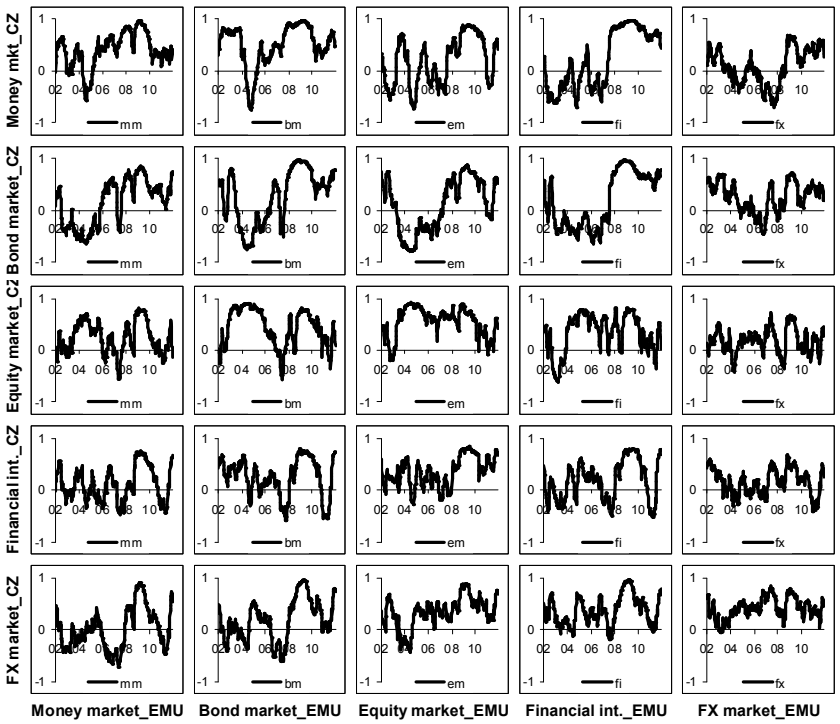
Note: Bold line is the mean value of draws of volatility process using Gibbs sampler; the dotted lines denote 1 s.d. posterior bands.

Source: Authors' calculations.

It seems that the degree of spillover depends strongly on the level of stress, i.e., the intensity of the transmission mechanism itself is given by the size of the shock. Due to the length of our time series it is difficult to evaluate if financial integration contributed to more intensive transmission of financial stress. The estimated volatility of the residuals is depicted in *Figure 7*. We observe that the variance of the residuals is highest during times of elevated financial stress. This shows the uniqueness of the financial crisis. The sovereign debt crisis, while still severe, has a far more limited impact.

Until now we have considered the development of the overall index. To assess the time-varying linkages between individual markets we use EWMA correlation analysis, which was already presented in the section dedicated to aggregation techniques. We observe a substantial increase in correlation between most markets after 2009 (the positive values in *Figure 8*). Only the Czech stock market exhibits a positive and stable correlation with most of the euro area markets, supporting the view of strong volatility spillover. This finding to a certain extent complements the current literature on volatility spillover between the stock markets of advanced countries and the Czech Republic. Egert and Kočenda (2011) did not find any strong correlation during a trading day prior to the crisis, whereas spillovers as well as macroeconomic

Figure 8 Cross Correlation between Segments of the Financial Market (Czech vis-à-vis Euro Area)



Note: Time varying correlations between five segments of the Czech financial market (money market, bond market, equity market, the market of financial intermediaries, foreign exchange market) and the five segments in the euro area.

Source: Authors' calculations.

announcements from developed markets do affect the Czech stock market according to Kočenda and Hanousek (2011). While these studies employed intraday data, our indicator is on a weekly basis, where adjustments in portfolios have time to realize fully.

With the exception of 2005, the money markets seem to be positively connected as well. Similar results apply for the Czech bond market, while financial intermediaries stand apart. At the end of 2011, when liquidity shortages due to the sovereign debt crisis substantially increased the level of financial stress in the euro area, the correlations between all the markets became positive, indicating the potential for another systemic crisis. Still, while the stock and bond markets as well as financial intermediaries are now highly correlated, the money markets seem to remain disconnected. The stress on the Czech money market remains contained compared to the euro area one, explaining the rather modest spillover of stress during the sovereign debt crisis.

6. Conclusion

Financial markets worldwide have become increasingly financially integrated over the past decade, and the financial crisis has revealed a peril of this trend—the spillover of systemic risk and contagion. This article adds some supportive evidence showing how the transmission of financial stress from the euro area to the Czech Republic has evolved over time. The analysis has shown that the degree of spillover depends strongly on the level of stress and that this mechanism is significant. The results are also in line with the current findings that the nature of the stress is important, as the sovereign debt crisis has so far had a limited impact on the Czech financial markets. Also, the Czech money market remains stable and the spillover from the euro area is rather limited. Our framework has proved useful in the analysis of complex developments in various markets and their international linkages. The CISS can clearly be used in other areas than financial stability. It can be employed for weekly monitoring of the financial markets for monetary policy purposes (or even as a part of risk management), as in times of financial instability, the effectiveness of the traditional transmission mechanisms can be limited. We also intend to incorporate knowledge of market conditions into analysis of the exchange rate, as a change in market conditions can lead to substantial withdrawals of funds from the emerging economies.

APPENDIX 1

Composition of the Financial Stress Indicator

Note: Some equivalents of the instruments used for the construction of the EMU index are not actively traded in the Czech Republic, so they were substituted by a proxy to show market conditions. The data sources are Bloomberg and Datastream.

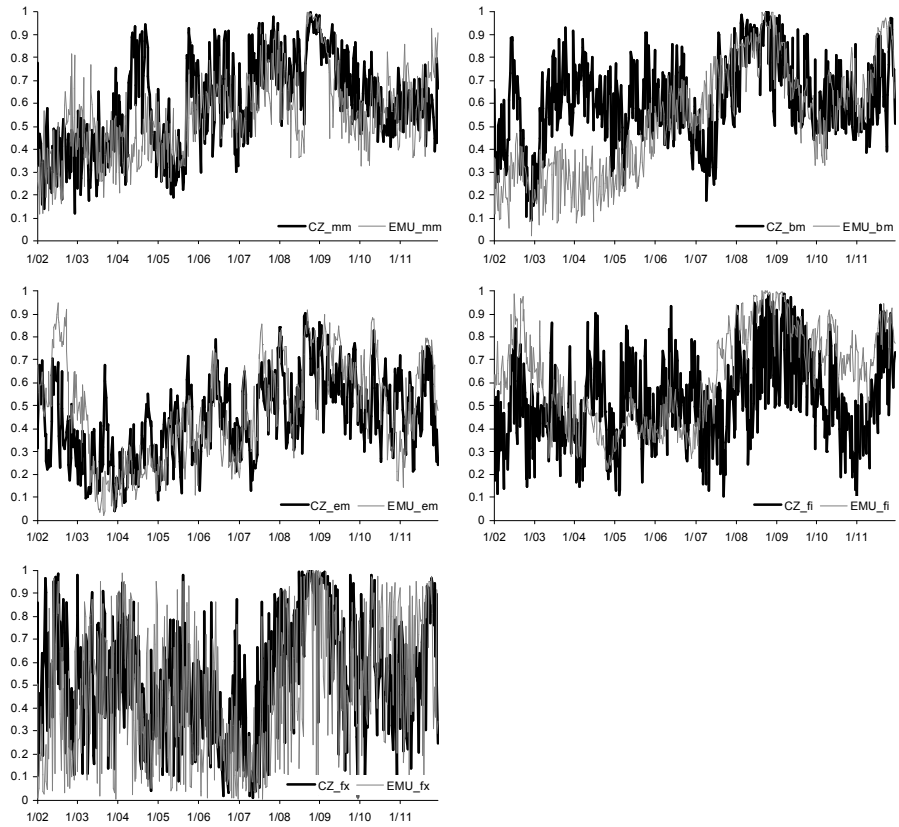
Euro area	Czech Republic
1. Money market	
Realized volatility of the 3-month EURIBOR; realized volatility calculated as the weekly average of the absolute daily rate changes.	Realized volatility of the 3-month PRIBOR: realized volatility calculated as the weekly average of the absolute daily rate changes.
Interest rate spread between the 3-month EURIBOR and 3-month French T-bills; weekly average of daily data.	Interest rate spread between the 3-month PRIBOR and the CZEONIA swap index; weekly average of daily data.
Liquidity: share of the ECB marginal lending facility in the total reserve requirements; weekly average of daily data.	
2. Bond market	
Realized volatility of the German 10-year benchmark government bond index: realized volatility calculated as the weekly average of the absolute daily yield changes; transformed by its recursive sample CDF.	Realized volatility of the Czech 5-year government bond index: realized volatility calculated as the weekly average of the absolute daily yield changes; transformed by its recursive sample CDF.
Yield spread between AAA-rated non-financial corporations and government bonds; weekly average of daily data.	5-year interest rate swap—Czech 5-year government bond index; weekly average of daily data; transformed by its recursive sample CDF.
10-year interest rate swap—German 10-year benchmark government bond; weekly average of daily data.	
3. Stock market	
Realized volatility of the non-financial sector equity market index calculated as the weekly average of the absolute daily log returns; transformed by its recursive sample CDF.	Realized volatility of the non-financial sector equity market index calculated as the weekly average of the absolute daily log returns; transformed by its recursive sample CDF.
CMAX for the non-financial sector equity market index; defined as $CMAX_t = 1 - \frac{x_t}{\max\left[x \in \left(x_{t-j} \mid j = 0,1,\ldots T\right)\right]}$ maximum cumulated loss comparing the level of a certain stock price index at time t with its highest value over the past 2 years of weekly data ($T = 104$), where x_t is the average weekly value of an index; transformed by its recursive sample CDF.	CMAX for the non-financial sector equity market index; transformed by its recursive sample CDF.
Stock-bond correlation: calculated as the weekly average of the difference between the 2-year (522 business day) and the 4-week (20 business day) correlation coefficients between the daily log returns on stock and bond indices.	Stock-bond correlation.

4. Financial intermediaries	
Realized volatility of the excess equity return (or idiosyncratic return component) of the banking sector index over the total market index; excess return calculated as the residual from an OLS regression of the daily log bank return on the log market return over a moving 2-year window (522 business days); realized volatility calculated as the weekly average of the absolute daily excess returns; transformed by its recursive sample CDF.	Realized volatility of the excess equity return (or idiosyncratic return component) of the banking sector index over the total market index.
Yield spread between A-rated financial and on-financial corporations; weekly average of daily data.	CMAX of financial sector index.
CMAX interacted with the inverse price-book ratio (book-price ratio) for the financial sector equity market index; they are both transformed by CDF and the final value is taken as the square root.	
5. Foreign exchange market	
Realized volatility of the USD/EUR, JPY/EUR, GBP/EUR exchange rates: realized volatility calculated as the weekly average of the absolute daily log foreign exchange returns; transformed by its recursive sample CDF. The foreign exchange market sub-index is a weighted average of the three series, where the weights for the currencies are 0.6, 0.2, 0.2, respectively.	Realized volatility of the EUR/CZK, USD/CZK exchange rates. The weights are 0.6 and 0.4 for EUR and USD, respectively.

APPENDIX 2

Evolution of Sub-Indices

Figure A2 Evolution of Sub-Indices of Segments of the Financial System



Notes: mm = money market, bm = bond market, em = equity market, fi = financial intermediaries, fx = foreign exchange market

Source: Authors' calculations.

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