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HOW TO TRADE USING THE (SHANNONIAN) TRANSFER ENTROPY? AN APPLICATION FOR CENTRAL AND EASTERN EUROPEAN MARKETS

Abstract*. Transfer entropies have been frequently used in the quantification of statistical coherence between various time series with prominent applications in financial markets. The authors consider that (Shannonian) transfer entropy may be used to describe the functional linkages between financial markets, to detect various types of asymmetries in the interaction between two systems and, consequently, to distinguish between driving and responding forces in such interactions. This last property has relevance in trading diversified portfolios on multiple markets. The authors illustrate such application for a group of six Central and Eastern European markets. The results show that for a time span between 2001 and 2012, these markets are dominated from the viewpoint of net information flows by WIG and S&P 500 indexes. The article reports the performances for individual portfolios which mimic the indexes' structure as well as for a global portfolio with weights based on individual net information flows.*

Keywords: *Financial markets, (Shannonian) transfer entropy, Global portfolio, CEE.*
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1. BACKGROUND AND RELATED LITERATURE

Interest in emerging markets has been growing and literature highlights the benefits of international portfolio diversification on emerging markets. Still, despite the benefits of investing on emerging markets, these stocks represent just a very small

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share of investors' equity holdings when relative stock market capitalization is taken into account.

The stock exchanges of Central and Eastern Europe (CEE) are relatively small emerging markets, still underdeveloped and economically unimportant compared to western stock markets; many of which (like Tallinn, Riga or Bratislava) still belong to the group of smallest exchanges in the world. The best developed markets among the CEE countries are the markets in the Czech Republic, Hungary and Poland, with market liquidity comparable to Western European stock markets.

The official markets and partly the regulated markets have rather strict listing requirements allowing foreign investors to have relatively low information costs on the official market segment. With the exception of Warsaw Stock Exchange, only a minority of companies is listed on the official market, the unregulated free market having the highest number of listings. This may be due to overly strict listing requirements and high disclosure standards on the official market segment and partly on the regulated market. Companies listed on the official market are required to publish/disclose their financial information according to the International Financial Reporting Standards (IFRSs), but only some provide financial information in English. These relatively high standards entail additional costs for the listed companies. However, since the exchanges and companies in Central and Eastern Europe have to build up confidence in order to attract domestic and foreign investors these rules probably have a positive impact diminishing the information costs for investors.

The different regulatory requirements and institutional arrangements of the CEE exchanges induce relatively high overall transaction costs due to high information costs and low liquidity. This reduces the interest of foreign investors in CEE stocks.

Claessens et al. (2002) investigate the reasons for the migration of companies in emerging economies to international financial centers. Domestic companies do hardly use the exchanges for external funding. When the financial sector of an economy is successfully developed, the companies have increased opportunities to access international exchanges and, thus, the largest companies will go abroad (Schröder and Köke, 2002). This causes a reduction of liquidity for the domestic stock exchanges and diminishes the chances of these exchanges to develop successfully.

Harvey (1995) shows that "adding emerging market assets to the portfolio problem significantly shifts the investment opportunity set", and that risk adjusted returns are 50% higher after their inclusion in the portfolio, mainly due to market segmentation. In the pre-integration period, aggregate investment in emerging markets was a good strategy. Nowadays, emerging markets are very much integrated into world capital markets. The segmentation premium they enjoyed in the 80's had eroded, and in the post-integration period, passive indexing strategies are no longer enough to add value. Using diversified index funds of emerging market equities does not improve portfolio's performance as aggregate emerging markets act similar to other asset classes. Aggregate diversification across all emerging markets is no longer enough to create value. Thus, other strategies as country and stock selection strategies become imperative. Still, investment in emerging market equities can still be very valuable to global investors, as long as they do not simply buy an index of all emerging market countries, but instead select what they invest in.

The case of transition countries in Central and Eastern Europe (CEE) is a particular one and the literature investigating financial contagion in the respective economies is rather vague (usually focusing on Hungary, Poland and the Czech Republic) and no consensus has been reached in regard to the existence of financial contagion. Authors like Wang and Moore (2008) investigate the co-movement of the three major CEE markets mentioned above with the aggregate euro zone market and find that the increase in stock market co-movements can only be explained by financial contagion.

MacDonald (2001) was one of the first researchers to find evidence of cointegration of the CEE stock markets with mature stock markets such as Germany, the United Kingdom and the United States, fact partially confirmed by Syllignakis and Kouretas (2006).

Syriopoulos (2006) reveals that the international cointegration linkages of the stock markets of the CEE countries with developed stock markets are stronger than the intraregional linkages among the CEE stock markets. On the other hand, authors like Gilmore and McManus (2002) and Yuca and Simga-Mugan (2000) find that the CEE stock markets are not cointegrated. Such differences of opinions in the early literature can be justified by the structural instability of the long-term international cointegration linkages, due to financial crises (Jochum et al.,1999; Voronkova, 2004).

The study of Kizys and Pierdzioch (2011) shows that the Czech Republic showed the strongest correlation with the Western economies and that the intraregional linkages of the stock markets of the Czech Republic, Hungary, and Poland have considerably changed over time. The cointegration linkages with the U.S. stock market strengthened in terms of both fundamentals and speculative bubbles during the market jitters caused by the financial crisis of 2008. The financial crisis of 2008 hit hard the stock markets of the CEE countries. After an analysis of the CEE stock markets, Kizys and Pierdzioch (2011) conclude that the collapse of these markets during the recent financial crisis is likely to reflect both a correlated transatlantic deterioration of fundamentals and contagion effects due to the international spillover of speculative bubbles originating in the U.S. stock market.

Weller and Morzuch (2000) show that both historically and recently, default risk has been lower in CEE countries than in other emerging economies.

The acute need to describe the functional linkages between financial markets led recently to the use of econophysics' methods in quantitative finance. Econophysics is one of the active research areas where many statistical methods are applied to investigate financial systems. In the framework of econophysics, it has become steadily evident that market interactions are highly nonlinear, unstable and long-ranged. Also, it seems that all agents involved in a given stock market exhibit interconnectedness and correlations which represent an important internal force of the market. The correlation functions one uses to study the internal cross-correlations between various market activities, have two major limitations: they measure only linear relations, although it is clear that linear models do not faithfully reflect real market interactions and determine whether two time series have correlated movement (without indicating which series affects which).

Schreiber (2000) introduced the concept of (Shannonian) transfer entropy (STE) in order to measure dependency in time between two variables. The transfer entropy provides more detailed information concerning the excess (or lack) of information in various parts of the underlying distribution resulting from updating the distribution, on the condition that a second time series is known. In the key context of financial time series, the risk valuation of large changes, such as spikes or sudden jumps, is of crucial significance. Information entropies are primarily important because there are various coding theorems which endow them with an operational meaning, and not because of intuitively pleasing aspects of their definitions.

Kwon and Yang (2008) use the method of transfer entropy and focus quantitatively on the direction of information flow between the index data and the price of individual companies. They conclude that there is a stronger flow of information from the stock index to the individual stocks than vice versa, and that transfer entropy for both directions has positive correlations.

Marschinski and Kantz (2002) apply the transfer entropy method to the analysis of financial time series and calculate the information flow between the Dow Jones and DAX stock indices.

The effective transfer entropy (ETE) was originally introduced by Marschinski and Kantz (2002) and it was further substantiated in Syriopoulos (2006). The ETE, in contrast to the TE, accounts for the finite size of a real data set.

Transfer entropies have been frequently used in the quantification of statistical coherence between various time series with prominent applications in financial markets. The transfer entropy may be used in order to detect various types of asymmetries in the interaction between two systems and, consequently, to distinguish between driving and responding forces. Such property of the transfer entropy may be considered in trading diversified portfolios on multiple markets.

The transfer entropy for two discrete and stationary processes, I and J , measures how much the dynamics of the process J influences the transition probabilities for process I (Kwon and Yang, 2008a, 2008b).The transfer entropy may be used to detect asymmetry in the interaction between two systems and to distinguish driving and responding elements (Kwon and Oh, 2012). Transfer entropy is a model-free measure estimated as the *Kullback-Leibler distance* between transition probabilities. One major advantage of such measure is that allows quantifying the information transfer without linear dynamics restrictions (Dimpfl and Peter, 2012).

Based on this literature, we formulate the following research hypothesis:
H: There are information flows between and within developed and CEE stock markets, which, due to information imperfections, may be used to establish efficient trading rules and may be involved in portfolio management operations.

2. METHODOLOGICAL FRAMEWORK

The model

Suppose that each individual market M_i is formed by "bounded rational" agents who are trading N_i homogenous financial assets. As key decisional variables involved in the choice of their portfolio' structures, these agents consider the costs, returns and risks associated with various types of financial assets, as well as the available incomes from own and borrowed sources.

If the investors are "neutral to risk", then the portfolio optimization objective will consist in ensuring a "balanced" return-to-risk ratio. Also, in order to minimize the transaction costs by preserving the chosen structure over a multi-period management time horizon, the agents will consider not only the current but also the forecasted values of the involved variables. The dynamic choice of portfolio' structure problem for the current period t on a particular market $M1$ can be formally described as:

$$\begin{cases} \forall\ x^{M1}_{it} \geq \lambda^{M1}_{it},\ \forall\ \lambda^{M1}_{it} \geq 0, \sum_{i=1}^{N_1}\sum_{j=1}^{t} x^{M1}_{it} = 1 \\ \sum_{i=1}^{N_1}\sum_{j=1}^{t} x^{M1}_{ij}\left(c^{M1}_{ij} + c^{M1*}_{ij}\right) + \sum_{l=1}^{D}\sum_{j=1}^{t}\left(k^{M1}_{lj} + k^{M1*}_{lj}\right) + \sum_{s=1}^{M}\sum_{j=1}^{t}\left(L^{M1}_{sj} + L^{M1*}_{sj}\right) = \\ = \sum_{u=1}^{Z}\sum_{j=1}^{t}\left(Y^{M1}_{uj} + Y^{M1*}_{uj}\right) + \sum_{l=1}^{D}\sum_{j=1}^{t}\left(B^{M1}_{lj} + B^{M1*}_{lj}\right) \\ \dfrac{\sum_{i=1}^{N_1}\sum_{j=1}^{t} x^{M1}_{ij}\left(\eta^{M1}_{ij} + \eta^{M1*}_{ij}\right)}{\sum_{i=1}^{N_1}\sum_{j=1}^{t} x_{ij}\left(R^{M1}_{ij} + R^{M1*}_{ij}\right)} \rightarrow MAX \end{cases}$$

Hence x are the weights of an individual asset i, λ are the "strategic" assets (the assets that are included at least at a minimal level in order to "anchor" the portfolio); c are the costs associated with trading and holding the assets; k are the weighted costs of borrowed financial resources; L are the liquid resources kept in portfolio for prudential and speculative reasons, Y are the net incomes from work and capital, from the current period or thesaurized from previous periods; B is the amount of borrowed resources, η are the returns of assets and R their associated risks. * denotes the forecasted levels of the involved variables.

The anticipations are formed according to a mixed mechanism, which incorporates information about past values, all the available and relevant current information (including the forecasting errors from past periods) as well as expectations about the future dynamics of determinant factors. Thus, the expectations about the assets' costs, returns and risks, *c, η, R* can be described as:

$$E\ \ c^{M1}{}_{t+1}\ = h\ \sum_k c^{M1}{}_{t-k}; INF^{M1}{}_t; E\ \ INF^{M1}{}_{t+1}\ \ ;\psi^1{}_t; \sum_{i=t-k+1}^{t} \varepsilon^{M1}{}_{1i}{}^2$$

$$E\ \ \eta^{M1}{}_{t+1}\ = h\ \sum_k \eta^{M1}{}_{t-k}; INF^{M1}{}_t; E\ \ INF^{M1}{}_{t+1}\ \ ;\psi^2{}_t; \sum_{i=t-k+1}^{t} \varepsilon^{M1}{}_{2i}{}^2$$

$$E\ \ R^{M1}{}_{t+1}\ = h\ \sum_k R^{M1}{}_{t-k}; INF^{M1}{}_t; E\ \ INF^{M1}{}_{t+1}\ \ ;\psi^3{}_t; \sum_{i=t-k+1}^{t} \varepsilon^{M1}{}_{3i}{}^2 \qquad 2$$

Here *INF* denotes an indicator of all information regarding the vector of returns' determinants, *Z*, that can be collected from the market; ψ are variables capturing the subjective components of the expectations (related to psychological factors) while ε^2 are past forecasting errors. If there are free capital movements and agents hold internationally diversified portfolios, then, in the formation of the anticipations, should be taken into account the information about not only the individual market on which the financial assets are traded, *M1*, but also the other markets, *M2*, which are functionally interrelated:

$$E\ \ INF_{t+1}^{M1}\ = E\ \ Z_{t+1} \Big| INF_t^{M2} \qquad 3$$

Thus, the "solutions" of the optimization problem for one market, i.e. the optimal structure of the portfolio, $x^s{}_{M1_{it}}$ are depending not only on the information about this market but also on the information collected from the other markets:

$$x^{M1^s}{}_{it} = x^{M1^s}{}_{it} \Big| INF_t^{M1}, INF_{t-1}{}^{M1}, ..., INF_{t-k+1}{}^{M1}, INF_t^{M2}, INF_{t-1}{}^{M2}, ..., INF_{t-k+1}{}^{M2} \qquad 4$$

If, in the case of the different markets, the information is asymmetric, there may appear arbitrage opportunities. Such operations will lead to shifts in the portfolios' structure and will trigger new information flows. If each individual market is characterized by distinctive frictionary factors and imperfect information issues, then these flows will display an asymmetric configuration.

One important testable consequence of this framework is the existence of information flows between interrelated markets. Thus, the aim of the next section is to describe a methodology able to quantify such flows.

The transfer entropy

In order to identify causal interactions, an asymmetric measure must be involved.

For instance, such measure can be provided by the "transfer entropy" (Schreiber, 2000). Formally, the transfer entropy can be defined (see Jizba et. al., 2012:14) as:

$$T_{Y\to X}(m,l) = H\left(X_{t_{m+1}} \middle| X_{t_1}\cap X_{t_2}\cap X_{t_3}\ldots\cap X_{t_m}\right) - H\left(X_{t_{m+1}} \middle| X_{t_1}\cap X_{t_2}\cap X_{t_3}\ldots\cap X_{t_m}\cap Y_{t_{m-l+1}}\cap\ldots\cap Y_{t_m}\right) =$$
$$= I\left(X_{t_{m+1}}; X_{t_1}\cap X_{t_2}\cap X_{t_3}\ldots\cap X_{t_m}\cap Y_{t_{m-l+1}}\cap\ldots\cap Y_{t_m}\right) - I\left(X_{t_{m+1}}; X_{t_1}\cap X_{t_2}\cap X_{t_3}\ldots\cap X_{t_m}\right) \quad (5)$$

In other words, the transfer entropy represents:

+ Gain of information about $X_{t_{m+1}}$ *caused by the whole history of X and Y up to time* t_m

− Gain of information about $X_{t_{m+1}}$ *caused by the whole history of X up to time* t_m

= Gain of information about $X_{t_{m+1}}$ *caused purely by the whole history of Y up to time* t_m.

For two concurrently sampled time series *X* and *Y*, the (Shannonian) transfer entropy from *Y* to *X*, $T_{Y\to X}(k,l)$, can be expressed as:

$$T_{Y\to X}(k,l) = \sum p\left(x_{t+1} \middle| x_t^{(k)}, y_t^{(l)}\right) \log_a \frac{p\left(x_{t+1} \middle| x_t^{(k)}, y_t^{(l)}\right)}{p\left(x_{t+1} \middle| x_t^{(k)}\right)} \quad (6)$$

It can be noticed that the most common settings of the parameters imply *k=l=1*. However, other time frames may be considered depending on the time structures of the involved variables.

In order to implement the transfer entropy estimation, we assimilate the probabilities with the relative data frequencies. The whole series is divided into *N* discrete bins and to every bin is assigned a sample data value. The number of data points per bin divided by the length of the time series constitutes the relative frequency. Obviously, the estimation depends on the number of bins chosen (the so-called "alphabet length"). To ensure some comparability with previous results (see for instance Kwon and Yang, 2008a, 2008b, Jizba et. al., 2012), we conduct calculations at a pre-fixed alphabet length $N = 3$. More precisely, for the log returns of indexes, $r_t = \ln(P_t) - \ln(P_{t-1})$, we define the discrete partition A_t as: $A_t=2$ if $r_t>0$ ("upward move"), $A_t=1$, if $r_t<0$ (" downward move"), and, respectively, $A_t=0$ if $r_t>0$ ("flat"). By applying this procedure, we obtain unequal probabilities for the three states, which enable us to highlight some of markets' intrinsic mechanisms. Consequently, we estimate the transfer entropy for all possible pairs of indexes.

Based on such estimations, the results are used to construct the *net information flows* (the outgoing minus incoming transfer entropy), *NIF*, and we seek to determinate the dominant and subordinate flows.

Furthermore, we involve from the *N* considered markets the information dominant ones, *M* (the markets for which $NIF^M = \max_{i=1..N} NIF_i$) as to generate trading signals for the subordinate markets. With this purpose, we consider a simple rule based on moving averages constructed on a rolling window *w*, $MA^M(w)$, and applied on the dominant indexes, such as:

Entry long, at current period t, when $MA^M_t(w) > MA^M_{t-w+1}(w)$ *and hold the trading position for a pre-determined trading horizon th.*

Such rule implies an automatic exit from the trading positions at the end of the *th* trading period regardless of the outcomes. The length of the window, *w*, as well as this trading period may be selected by searching in a reference interval (between w_{min} and w_{max}) according to an evaluation rule for the results (for instance, by choosing that pair of window length and trading period for which a maximum average return per trade is obtained).

International data

Data represents daily close values for the indexes of the analyzed markets. The data set was obtained by combining data from the Yahoo financial portal and from http://www.stooq.com which provides financial data. The gathered data was synchronized by removing periods without trading activity (weekends, night time and holidays) for the stock exchanges taken into account. Of course, such procedure has the disadvantage that the observations which are separated in real time may become close neighbors in the synchronized time series. However, there are only a few observations comparing with the regular data and so the procedure does not lead to significant statistical errors.

3. RESULTS AND DISCUSSION

The transfer entropy is estimated for all possible pairs of indexes. The results are reported in Exhibit 1. For the full sample, among the Central and Eastern European indexes, the most substantial transfers are the ones between WIG, PX, BUX and ATX. The weakest information linkages are attached to SAX and RTS indexes. For the developed markets, the DAX index seems to be the least connected to the others.

In order to identify the structural changes in the involved processes, the data sample is splitted in two sub-periods (2001-2007 and, respectively, 2007-2012) and the transfer entropy is re-estimated for each sub-period. The outcome indicates that the current financial turbulence has led to a decrease in the levels of transfer entropy. This “decoupling” evolution may be viewed as an expression of the increased uncertainty about markets’ evolutions, changes in trading strategies and portfolios, according to higher levels of risk aversion.

Exhibit 1. Transfer entropy for Central and Eastern European indexes

A) Panel “A”: full sample (01/10/2001- 10/01/2012)

$Y \to X$	SAX	ATX	PX	WIG	BUX	RTS
SAX		0.00007	0.00059	0.00008	0.00023	0.00122
ATX	0.00091		0.00089	0.00032	0.00022	0.00050
PX	0.00080	0.00049		0.00007	0.00081	0.00104
WIG	0.00079	0.00598	0.00753		0.00686	0.00616
BUX	0.00116	0.00026	0.00028	0.00003		0.00052
RTS	0.00057	0.00043	0.00034	0.00024	0.00101	
SP500	0.00054	0.00437	0.00841	0.00100	0.00361	0.00527
FTSE100	0.00062	0.00016	0.00186	0.00026	0.00028	0.00064
CAC40	0.00042	0.00023	0.00131	0.00017	0.00047	0.00042
DAX	0.00077	0.00056	0.00098	0.00000	0.00026	0.00027

(continuation)

$Y \to X$	SP500	FTSE100	CAC40	DAX
SP500		0.00550	0.00566	0.00406
FTSE100	0.00055		0.00020	0.00096
CAC40	0.00083	0.00075		0.00029
DAX	0.00051	0.00049	0.00021	

B) Panel “B”: subsample (01/10/2001- 01/09/2007)

$Y \to X$	SAX	ATX	PX	WIG	BUX	RTS
SAX		0.00045	0.00139	0.00014	0.00054	0.00135
ATX	0.00151		0.00046	0.00092	0.00026	0.00070
PX	0.00143	0.00089		0.00062	0.00087	0.00130
WIG	0.00085	0.00485	0.00437		0.00758	0.00664
BUX	0.00108	0.00001	0.00135	0.00035		0.00069
RTS	0.00119	0.00103	0.00097	0.00079	0.00178	
SP500	0.00096	0.00530	0.00773	0.00177	0.00582	0.00821
FTSE100	0.00127	0.00058	0.00122	0.00051	0.00071	0.00126
CAC40	0.00051	0.00065	0.00088	0.00030	0.00091	0.00119
DAX	0.00142	0.00055	0.00042	0.00015	0.00013	0.00049

(continuation)

$Y \to X$	SP500	FTSE100	CAC40	DAX
SP500		0.00954	0.00864	0.00640
FTSE100	0.00067		0.00072	0.00175
CAC40	0.00189	0.00050		0.00033
DAX	0.00092	0.00010	0.00034	

C) Panel “B”: subsample (01/09/2007-10/01/2012)

$Y \to X$	SAX	ATX	PX	WIG	BUX	RTS
SAX		0.00057	0.00065	0.00016	0.00030	0.00222
ATX	0.00134		0.00349	0.00003	0.00101	0.00183
PX	0.00122	0.00083		0.00052	0.00168	0.00241

WIG	0.00123	0.00747	0.01391		0.00646	0.00824
BUX	0.00176	0.00113	0.00158	0.00028		0.00116
RTS	0.00115	0.00064	0.00154	0.00061	0.00090	
SP500	0.00065	0.00407	0.01124	0.00048	0.00208	0.00405
FTSE100	0.00061	0.00057	0.00376	0.00067	0.00045	0.00080
CAC40	0.00089	0.00035	0.00431	0.00014	0.00023	0.00150
DAX	0.00089	0.00108	0.00396	0.00013	0.00055	0.00101

(continuation)

$Y \to X$	SP500	FTSE100	CAC40	DAX
SP500		0.00287	0.00317	0.00217
FTSE100	0.00038		0.00100	0.00224
CAC40	0.00001	0.00129		
DAX	0.00017	0.00111	0.00036	

Comparing the transfer entropy values between developed and emergent markets, it appears that the latter markets are receiving more information from S&P 500 than from the continental markets. These results are consistent with other evidences from the literature. For instance, as Kizys and Pierdzioch (2011:154) note: "*Transatlantic* cointegration linkages with U.S. fundamentals and U.S. speculative bubbles strengthened to a much more significant extent than *continental* cointegration linkages with fundamentals and speculative bubbles estimated for Germany and the United Kingdom. *Intraregional* cointegration linkages of speculative bubbles among the CEE countries also became stronger during the recent financial crisis, but there is hardly evidence that the crisis triggered stronger intraregional cointegration linkages of fundamentals". However, opposite to other findings (Syriopoulos, 2006), we have no confirmation of CEE stock markets' interactions with developed stock markets, stronger than the intraregional connections.

The *net information flows* for an individual index *X*, $NIF_X = \sum_i TE_{X \to i} - TE_{i \to X}$, provides a synthetic picture of the hierarchical relationships between markets. Exhibit 2 reports the corresponding values for the Central and Eastern European indexes.

Exhibit 2. Net inflows for Central and Eastern European countries (full sample: 01/10/2001- 10/01/2012)

Y→ All indexes	Net information flows
WIG	0.02658
SP500	0.01893
DAX	0.00203
FTSE100	0.00196
PX	0.00184
CAC40	0.00130
BUX	0.00097
ATX	0.00091
SAX	0.00065
RTS	0.00049

Usually, in the estimation of the transfer entropy, the order *(k,l)* is set to 1 for two reasons: firstly, to make computation faster and, secondly, to ensure an adequate sampling. Nevertheless, we explore the potential explanatory utility of higher-order transfer entropy by choosing various lengths of delays. The results are show in Exhibit 3.

Exhibit 3. Transfer entropy for various time frames

A) *k=3, l=5*

Y→ X	SAX	ATX	PX	WIG	BUX	RTS
SP500	0.00169	0.00135	0.00123	0.00126	0.00116	0.00176
FTSE100	0.00118	0.00100	0.00111	0.00092	0.00095	0.00146
CAC40	0.00160	0.00136	0.00141	0.00123	0.00111	0.00174
DAX	0.00109	0.00117	0.00132	0.00104	0.00117	0.00116

B) *k=20, l=20*

Y→ X	SAX	ATX	PX	WIG	BUX	RTS
SP500	0.00398	0.00404	0.00461	0.00419	0.00391	0.00461
FTSE100	0.00378	0.00372	0.00459	0.00391	0.00362	0.00407
CAC40	0.00407	0.00375	0.00427	0.00372	0.00379	0.00459
DAX	0.00426	0.00415	0.00425	0.00417	0.00369	0.00416

C) *k=42, l=42*

Y→ X	SAX	ATX	PX	WIG	BUX	RTS
SP500	0.00846	0.00786	0.00827	0.00874	0.00799	0.00823
FTSE100	0.00773	0.00765	0.00781	0.00780	0.00762	0.00817
CAC40	0.00818	0.00777	0.00800	0.00792	0.00802	0.00839
DAX	0.00775	0.00771	0.00790	0.00774	0.00786	0.00832

Even if the absolute levels of transfer entropy increase, the overall hierarchy of the indexes does not change for higher delays. However, at higher orders, there is an augment in the relative impact of continental markets over Central and Eastern European ones (especially from the CAC 40 and FTSE100). This implies that the investors are reacting, firstly, to the new information arrived from the *transatlantic* and *regional* markets on "short-run" and, subsequently, to the news from the *continental* markets on "long-run".
Globally, these indexes are dominated, from the perspective of the information flows, by WIG and, respectively, S&P 500. A comparative analysis of the Central and Eastern European markets reveals some potential explanations for the key role played in the area by Poland' capital market (Exhibit 4). The significant level of market capitalization, relative higher levels of market' liquidity as well as good market turnovers, all these are based on sound regulatory and supervisory frameworks as well as on improved market mechanisms.

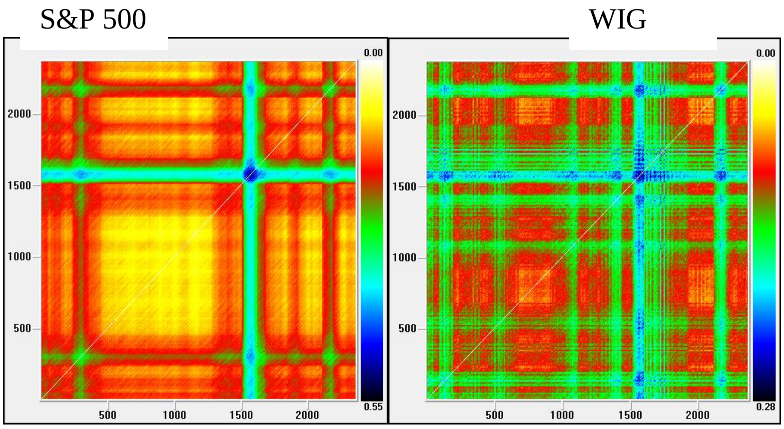
Exhibit 4. Main characteristics of Central and Eastern European markets (averages for 2000-2011)

	Czech Republic	Poland	Slovak Republic	Russian Federation	Austria	Euro area
Market capitalization of listed companies (% of GDP)	24.25	27.58	5.92	56.25	27.17	61.25
Stocks traded, total value (% of GDP)	14.00	11.17	0.83	33.58	12.42	72.00
Stocks traded, turnover ratio (%)	58.83	40.08	21.92	62.75	44.17	116.58

Source of data: World Bank (2013)

Since the distribution of colors over the recurrence plots for S&P 500 and, respectively, WIG (log) returns, which employ color-spectrum visualization for indexes, is not even, the null of truly random and without structure processes might be rejected for them. Thus, it can be argued that the returns for these information dominant indexes display a certain degree of predictability. Such predictability is a key requirement for using these indexes in order to evaluate the entry in trading opportunities for the considered markets.

Exhibit 5. Recurrence plots for the (log) returns of S&P 500 and WIG



Notes: the embedding dimension of 80 and the time delay of 1 for S&P 500 and, respectively, 36 and 2 are computed from the False Nearest Neighbors method and Average Mutual Information method.

Based on this, we identify the upward trends in WIG and S&P 500 and we generate the trading signals for the emergent indexes, according to the mentioned rule. Consequently, we estimate the quality of these signals. In order to obtain more realistic results, we consider a 0.5% trading fees from each entry, respectively, exit prices. The outcomes are reported in Exhibit 6.

Exhibit 6. Portfolios outcomes

A) Panel "A": full sample (01/10/2001- 10/01/2012)

	PX	BUX	SAX	RTS	ATX	*Global portfolio*
Average return per trade (%)	2.10	2.56	1.31	5.25	2.50	2.48
Standard deviation of returns (%)	7.19	8.27	7.46	12.61	7.09	6.54
Sharpe ratio	0.29	0.31	0.18	0.42	0.35	0.38
Sortino ratio	0.55	0.63	0.37	0.90	0.64	0.72
Number of trades	1123	1123	1123	1123	1123	5615

B) Panel "B": subsample (01/10/2001- 01/09/2007)

	PX	BUX	SAX	RTS	ATX	*Global portfolio*
Average return per trade (%)	2.35	2.92	1.63	5.73	2.81	2.80
Standard deviation of returns (%)	7.45	8.60	7.85	13.03	7.24	6.75
Sharpe ratio	0.32	0.34	0.21	0.44	0.39	0.41

Sortino ratio	0.60	0.70	0.45	0.96	0.70	0.79
Number of trades	974	974	974	974	974	4870

C) Panel "B": subsample (01/09/2007-10/01/2012)

	PX	BUX	SAX	RTS	ATX	*Global portfolio*
Average return per trade (%)	0.43	0.17	-0.81	2.13	0.42	0.38
Standard deviation of returns (%)	4.90	5.04	3.32	8.89	5.59	4.40
Sharpe ratio	0.09	0.03	-0.24	0.24	0.07	0.09
Sortino ratio	0.16	0.06	-0.37	0.44	0.13	0.15
Number of trades	149	149	149	149	149	745

Notes: The global portfolio is composed by PX, BUX, SAX, RTS, and ATX portfolios. The weights are computed as the ratio between individual information flows as reported in Exhibit and their global level. The rolling window w is set equal with 11 successive trading days and the pre-determined trading horizon th is equal with 15 successive trading days. A 0.5% trading fees is applied for each entry and, respectively, exit trade.

The best results are obtained in terms of return-to-risk Sharpe and Sortino ratios for RTS and BUX indexes, while the worst appear to be the ones for SAX. The average returns per trade are almost five times larger for RTS in comparison with SAX.

Also, we evaluate the performances of a full portfolio composed by all indexes. The allocation weights in the structure of such portfolio, α_i, for an individual index *i*, are established according to the relative *net information flows*:

$$\alpha_i = \frac{NIF_i}{\sum_{i=1}^{N} NIF_i} \qquad 7$$

The idea behind this allocation mechanism is to attach higher weights to the markets which are net information suppliers. Thus, the composition of the full portfolio will reflect the information hierarchy between markets, aiming to ensure a higher degree of structural stability.

The figures from the last column of Exhibit 5 highlight that such a global portfolio performs relatively well with the return-to-risk ratios being approximately equal with almost the double of the worst performances. The assessment of the full portfolio results does not count for the risks induced by the markets' interactions. Still, the methodology used in the choice of weights addresses, indirectly, this issue, since it is based on the information flows. Thus, it might be argued that the structure of this portfolio is relatively stable over time.

Furthermore, in order to check the robustness of the results, we re-estimate these for two sub-periods (2001- end of 2006, and respectively 2007-2012). It appears that there are significant differences in the configuration of the performances between these sub-periods. While for the first reference period, the return-to-risk ratios are somehow better compared to the full sample, the situation is worsening for the second sub-period with looses on the SAX market and net returns being less than one quarter of the full sample. Hence, the financial turbulence is wiping out a substantial amount of performances. Also, there are less trading signals in the second sub-period. Still, important differences exist in indexes' time behavior. The relative smallest looses are in the case of RTS. Since this market has the lowest level of net information flow, this may suggest that such evolutions are not only the direct consequence of markets' institutions and mechanisms, but also a product of the integration in the international capital movements.

4. SUMMARY, IMPLICATIONS AND EXTENSIONS

We find that the (Shannonian) transfer entropy may be used to quantify the information flows between markets and to implement multi-markets trading strategies. We empirically test this for a group of Central and Eastern European markets. These markets appear to be dominated by the information which flows from WIG and S&P 500 indexes. We estimate the outcomes of a trading strategy, based on the changes on these markets, both for the other individual markets and for a global portfolio. The weights of this global portfolio are chosen based on the relative *net information flows* and its structure is kept unchanged for the entire analysis period. The best results are obtained in terms of return-to-risk ratios for RTS and BUX indexes. However, these results are less robust over time and are sensitive to the financial turbulence climate. Overall, it appears that the degree of information openness and integration in the international flows are key determinants of the performances of a trading strategy based on information linkages.

Such results can be viewed as being relevant not only for practitioners, but also from a conceptual point of view, as they highlight the asymmetric nature of the interactions between markets. Thus, this approach may be seen as a possible step in building up a broader analysis of market imperfections, as these can emerge under the impact of internal frictionary factors and as a consequence of information "contamination" processes.

This outcome may be extended in several ways. One direction for follow-up research would be to involve other types of transfer entropy (for instance, the Rényi's information transfer as in Jizba et. al., 2012). A second way of extending the research would be to involve some explicit determinants of information transfers (such as the variables from the dynamic choice of portfolio' structure problem or other more macroeconomic variables). Thirdly, other types of more sophisticate trading strategies may be considered. Finally, institutional characteristics of the markets may be considered. By using transfer entropies with more complex constructive features and by considering a broader explanatory framework, this approach may be further enriched.

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