ADVANCE – Centro de Investigação Avançada do ISEG

"Electricity Market Interconnections and Electricity Price Volatility"

Nuno Fonseca
Citigroup Global Markets
Canada Square, Canary Wharf
E14 5LB London, UK
Email: nuno.fonseca@citi.com

João Duque
Technical University of Lisbon
School of Economics and Management
Rua Miguel Lupi, 20
1249-078, Lisbon, Portugal
jduque@iseg.utl.pt
(Contact Author)

WORKING PAPER N. 7 /2008

November, 2008

Abstract

In this paper, we present a model of changes in electricity price returns in the context of interconnected electricity markets. This model predicts an inverse relationship between the increase in interconnection capacity and the volatility of price returns in the corresponding electricity markets. This means that an increase of interconnection between two markets leads to a decrease in the volatility of their prices. We support our model with empirical results from the Australian, European and USA electricity markets. The results suggest that this inverse relationship between interconnection and volatility exists, meaning that when markets tend to be physically interconnected, variance tends to be reduced.

Key words: Electricity Price Modelling; Price Returns Volatility; Physical Electricity Market and Volatility.

JEL Classification: F15, F36 and Q41.

Financial support granted by the Fundação para a Ciência e a Tecnologia (FCT) and the Programa Praxis XXI is gratefully acknowledged.

1. INTRODUCTION

In recent years, the growth of electricity markets has presented new challenges to engineers and economists. A growing number of interconnected electricity markets with different structures, regulations and players has emerged all over the world. The main product in these markets is electric energy, and the need to hedge against price risk, in this new environment, has drawn the attention of professionals and academics to the evolution of prices and the features behind them.

As noted by Carr and Wu (2003) among others, a good knowledge of the price process is essential in the evaluation of any derivative - such as an option to buy or sell electricity -, in order to provide adequate risk hedging solutions. Although the Black and Scholes (1973) classic model continues to be widely used in option pricing, several authors have pointed out some problems in the model, especially when applied to energy derivatives. As an example, Carr and Wu (2004) emphasize three motives assumptions in the Black-Scholes model that make it inadequate to power options: the Geometric Brownian Motion assumption, the assumption of continuity in the price process, and the assumption of normality in the probability distributions. In addition, the volatility itself seems stochastic, and there is evidence of correlation between returns and volatility.

Interconnected electricity systems exist all over the world. In Europe, a single synchronized system spans from Portugal to Bulgaria. However, the level of interconnection, i.e. transfer of power capacity, is very small in some regions, resulting in bottlenecks, while in others it is very high, smoothing the process of power capacity flow, with expected price impact. Therefore we hypothesize that physical market interconnection may play a significant role when modeling price returns volatility. The aim of this work is to show that besides simple arbitrage benefits when exploiting adjacent market price differences, increase in the interconnection level has a significant impact in terms of price risk. We suspect that the increase of transfer of power capacity will lower the volatility of electricity prices. If this is so, our results will perform an important role when pricing risk management instruments like power options.

The paper is organized as follows. In section two we present some electricity price characteristics and explain the impact of market interconnections. In section three we present our model and in section four we present the database. We finish the document by discussing our empirical findings and summarizing our results in the conclusion.

2. ELECTRICITY PRICES AND ELECTRICITY MARKETS CHARACTERISTICS

Several authors have analyzed the behavior of electricity prices. Among others, Nogales et al. (2002) identify the most important characteristics as high frequency of data observations, non-constant mean and variance along time, multiple seasonality (daily, weekly and annual), high price volatility; and the presence of jumps in the price process.

We can observe these characteristics in most electricity markets. High frequency refers to typical daily variations, for instance, from 14 to 35 €/MWh, a 150% variation. In most commodities, this daily price variation would be inconsistent, which is not the case in the electricity markets, because of the non-storability of electricity. This large variation in prices translates into a large volatility. As noted by Huisman and Mahieu (2003), it is usual to observe daily volatilities of 29% in electricity markets compared to typical 20% annual volatilities in other financial products.

We can explain seasonality by structural changes in supply and demand. Supply is usually dependent on hydro resources, which depend on climate changes that also affect the demand. The occurrence of unpredictable events, such as an outage, or sudden abnormal temperature changes explains the presence of jumps or spikes in prices.

Knowledge of the features that have an impact on the formation of electricity prices is crucial in the definition of an adequate price process.

The price of electricity should have a positive correlation with consumption due to increasing marginal costs of production. Therefore, as the load increases, the price is also likely to increase, and the presence of daily, weekly, and seasonal patterns is expected. Li and Flynn (2004) study those patterns and present evidence that there are different degrees of correlation between electricity price and consumption and different kinds of patterns from market to market.

Apart from those regions where natural barriers like seas or oceans are present, electricity systems tend to be interconnected all over the world. In Europe, for instance, a single synchronized system spans from Portugal to Bulgaria. In spite of that, the level of interconnection, i.e. physical transfer of power capacity, is quite small in some regions, resulting in bottlenecks. These are expected to have an impact in price smoothing when analyzing adjacent market price formations. The objective of this paper is to show how changes in interconnection levels have an impact on price behavior, namely in terms of price risk. More objectively, we argue that an increase in power transfer capacity will lower the volatility of electricity prices.

This is critical when pricing risk management contracts like options. For example, we may expect a decrease in the price of an energy derivative (call or put option) in one market as the level of interconnection with other markets increases. Transmission lines are the only possible means to exercise arbitrage in real time but, as they are physical systems, they are subject to failure and maintenance periods, on top of physical restrictions that theoretical models usually assume not to exist. As a result, reinforcements of existing lines as well as the construction of new lines can also change the level of interconnection with immediate impact on price volatility.

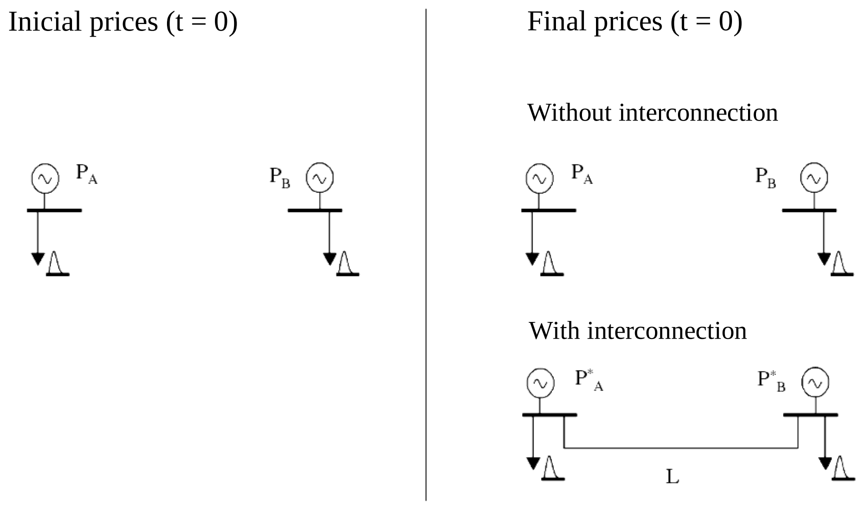

Figure 1 – Example of setting up an interconnection between electricity markets.

Figure 1 shows what is supposed to happen when a new link is constructed between two separate markets. When markets are completely distinct, instant arbitrage mechanisms are not possible in the spot markets of both regions. However, as soon as we link them and as soon as we let the price mechanisms flow between, them prices will tend to converge, limited by the physical capacities opened by the linkage mechanism.

3. MODELLING CHANGES IN ELECTRICITY PRICES IN INTERCONNECTED MARKETS

3.1. Modelling Price Returns

In market economies, electricity price is governed by the match of supply and demand and, as in any other markets, it is plausible to assume that the price returns show a finite average and variance.

The existence of an interconnection promotes arbitrage possibilities between interconnected markets. Therefore, as the level of interconnection between different electricity markets increases, their price returns will tend to converge. This is shown by

Figure 1, which illustrates when a new link is built between two markets that were previously segregated (time zero). At time one, we could devise two possibilities: without the interconnection prices would remain the same; with the interconnection, i.e. after the link was established, and assuming that the link was strong enough to not impose any power transfer constraint, prices would converge.

That is, the interconnection between electricity markets favors arbitrage. Therefore, the differences in prices in the second instant (t = 1) will tend to zero, depending on transaction costs and power transfer capacity. Nevertheless, even assuming that the flow mechanism was slowed down by some strangulation on power transference capacity, or given imperfect markets as a result of transaction costs, the increase of interconnection should always support an increase in price returns correlation. Li and Flynn (2004) showed that in deregulated electricity markets that are close and connected by transmission lines, prices tend to equalize.

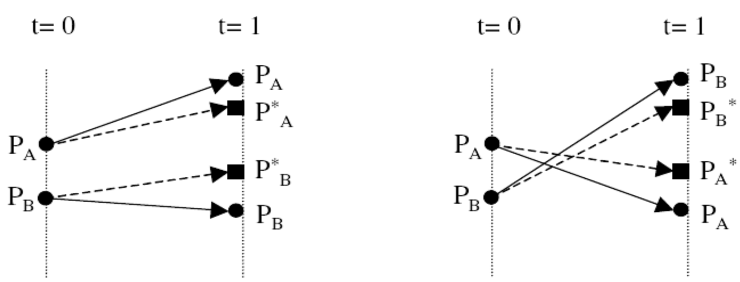

Figure 2 – Two examples of prices evolution with and without interconnection.

As shown in Figure 2, we will assume that price differences between two markets that became interconnected will always become smaller than if they were kept unconnected. Let P_A and P_B stand for the electricity price in market A and B respectively, assuming that A and B are not connected, while P_A^* and P_B^* will stand for the electricity price in both markets after an interconnection has been established.

We start by assuming that:

Assumption I – after an interconnection is established, prices in different markets will always be closer than they would be without the interconnection, whatever the change in the price:

$$\left|P_A^{t=1} - P_B^{t=1}\right| > \left|P_A^{*,t=1} - P_B^{*,t=1}\right| \qquad \textbf{eq. 1}$$

Next, we define price returns as the result of price comparison following the assumptions established by equation 1 (please refer to Figure 2 also). The dotted lines in Figure 2 are associated with price changes, assuming that an interconnection between markets was established, while the continuous lines are associated with price changes in the absence of any interconnection. If, in market A, electricity prices start at level $P_A^{t=0}$ at time 0, they can become either the new level $P_A^{*,t=1}$ if an interconnection is established, or the new level $P_A^{t=1}$ if an interconnection is not established. Therefore, we would consider two price returns for each market, starting at a single price level in each market and reaching one of two different price levels per market as a result of establishing an interconnection between markets or not.

$$\begin{cases} R_{PA} = \ln\left(\dfrac{P_A^{t=1}}{P_A^{t=0}}\right) = p_A^{t=1} - p_A^{t=0} \\ R_{PB} = \ln\left(\dfrac{P_B^{t=1}}{P_B^{t=0}}\right) = p_B^{t=1} - p_B^{t=0} \end{cases} \qquad \textbf{eq. 2}$$

$$\begin{cases} R_{PA}^{*} = \ln\left(\dfrac{P_A^{*,t=1}}{P_A^{t=0}}\right) = p_A^{*,t=1} - p_A^{t=0} \\ R_{PB}^{*} = \ln\left(\dfrac{P_B^{*,t=1}}{P_B^{t=0}}\right) = p_B^{*,t=1} - p_B^{t=0} \end{cases} \qquad \textbf{eq. 3}$$

After defining the price returns formulas in equations 3 and 4, and as a result of the assumption given by equation 1 (that is, prices in different markets will tend to converge after an interconnection is established) we will move to raise a second assumption:

Assumption II – electricity prices between adjacent markets tend to converge linearly:

$$\begin{cases} p_A^{*,t=1} = p_A^{t=1} + \alpha\left(p_B^{t=1} - p_A^{t=1}\right) \\ p_B^{*,t=1} = p_B^{t=1} + \beta\left(p_B^{t=1} - p_A^{t=1}\right) \end{cases} \qquad \textbf{eq. 4}$$

The simultaneous equations model presented in equation 5 is subject to the following constraints: a) initial prices have to differ from zero; b) $0 < \alpha < 1$ and $0 < \beta < 1$; c) $\alpha + \beta \leq 1$. This set of constraints prevents the model from providing an inversion in the magnitude of prices at time 1 (t = 1), allowing any possible adjustment combinations in prices.

As a consequence of assumptions I and II we may now establish corollaries I and II.

Corollary I: The absence of interconnection ($\alpha = 0 \quad \wedge \quad \beta = 0$) keeps price returns unchanged:

If $\alpha = 0 \quad \wedge \beta = 0$ => $\begin{cases} p_A^{*,t=1} = p_A^{t=1} \\ p_B^{*,t=1} = p_B^{t=1} \end{cases}$.

Corollary II: When an interconnection is established with no visible restrictions of power transfer capacity, or consumption tax differentials between markets ($\alpha + \beta = 1$), price returns will tend to converge to the same level. This would mean that no barriers or constraints would exist and that arbitrage arguments would hold fully.

If $\alpha + \beta = 1$ => $p_A^{*,t=1} = p_B^{*,t=1}$.

Assuming that $\beta = 1 - \alpha$, and replacing β in equation 5, it becomes $p_A^{*,t=1} = p_B^{*,t=1}$.

4. DATA

The data used in this paper consist of a series of daily average prices and consumptions of electricity as defined in Table 1.

Table 1 - Outline of the data series of daily average prices and consumptions of electricity.

Group	Market	Sampling Period
Australian	SA (South Australian) SNOWY (Snowy Mountains) NSW (New South Wales) QLD (Queensland) VIC (Victoria)	12-13-1998 to 12-31-2002
European	LPX (Leipzig Power Exchange) APX (Amsterdam Power Exchange) NordPool (Nordic Power Exchange) UK OMEL	06-16-2000 to 02-28-2001
USA/Canada	Canada Northern California Southern California PJM NEPOOL	05-01-1999 to 12-28-2000

The Australian data series contains daily electricity prices and volumes from 12-13-1998 to 12-31-2002 that is, 1480 consecutive days. This allowed us to estimate 1473 weekly returns, which corresponds to approximately 4 years of data. The Australian electricity markets present an excellent variability of price return correlations, from 0.0889 to 0.9657. This shows a diversity of interconnection level between each market. The European data series span from 06-16-2000 to 02-28-2001. This is a smaller interval consisting of 258 consecutive days, 251 weekly returns. Finally, for the USA and Canada electricity markets we considered the period between 05-01-1999 and 12-28-2000. This interval contains 608 days and allows the calculation of 601 weekly returns.

Daily electricity average prices and daily electricity consumptions were provided by Ying Lia and Peter C. Flynn from the University of Alberta, Canada.

5. EMPIRICAL RESULTS

The methodology used in this paper consists of a cross-section estimation of the relationship between joint volatility and the correlation of price returns. We also used some control variables as described in 5.1. Although it is not possible to have a physical measure of electricity markets, we assume that electricity price returns correlation is good proxy indicator for the interconnection level. Therefore, in conjunction with equation 6, we expect an inverse relationship between the price returns correlation and conjunct volatility. That is, as markets become more interconnected, we expect an increase in electricity price correlation and a decrease in conjunct volatility.

5.1. The Estimation Model

We tested two different estimation models. The first model is given by equation 6, where we regress the joint volatility of price returns for two different markets *i* and *j* $\left(\sigma_{p_i} + \sigma_{p_j}\right)$ against the correlation of price returns $\left(\rho_{p_i, p_j}\right)$, the correlation of consumption logarithmic differences $\left(\rho_{C_i, C_j}\right)$, the joint volatility of consumption logarithmic differences $\left(\sigma_{C_i} + \sigma_{C_j}\right)$ and the joint normalized average transaction volumes $\left(C_i + C_j\right)$. This model only considers a single period.

$$\left(\sigma_{p_i} + \sigma_{p_j}\right) = a_0 + a_1 \rho_{p_i p_j} + a_2 \rho_{C_i C_j} + a_3 \left(\sigma_{c_i} + \sigma_{c_j}\right) + a_4 \left(C_i + C_j\right) \quad \textbf{eq. 5}$$

The second model is given by equation 7. It additionally considers the day of the week effect through the inclusion of a dummy variable □□ with □0 for Sunday, □1 for Monday and so on.

$$\left(\sigma_{p_i} + \sigma_{p_j}\right) = b_0 + b_1 \rho_{p_i p_j} + b_2 \rho_{C_i C_j} + b_3\left(\sigma_{c_i} + \sigma_{c_j}\right) + b_4\left(C_i + C_j\right) + \sum_{k=0}^{5}\left(b_{5+k}\ \lambda_k\right) \qquad \textbf{eq. 6}$$

We set up three groups of electricity markets (Australian, European and USA/Canada). Within each group, all markets are physically interconnected.

5.2. Results

We present the results in Tables 2 and 3, using the estimations model given by equations 6 and 7. As expected, and in support of our hypothesis derived from Theorem I, a_1 and b_1 are negative in all the cases. That is, when joint volatility among markets increases, the correlation among electricity price returns tends to decrease. The *p*-value is below 0.05 for the European and Australian markets, showing that we can reject the null hypothesis for a zero coefficient at 5% significance level. In the USA and Canada, a_1 and b_1 are negative, but they are statistically insignificant. This may be partly explained by the weak direct physical interconnection between the California electricity markets and the east coast US markets. However, when we drop the variables that correspond to the least significant coefficients in equation 7 (b_2, b_3, b_4 and b_5) and rerun the regression equation on the same data, the coefficient b_1 becomes statistically significant at a 10% confidence level. The same happens when equation 7 is applied to the European data. When we drop the variable that corresponds to the least significant coefficient in equation 7 (b_2) and rerun the regression equation on the same data, the coefficient b_1 becomes statistically significant at a 5% confidence level.

Table 2 - Estimation results: model equation (6)

	Australian		**European**		**USA**	
Coefficient	Value	p-value	Value	p-value	Value	p-value
a_0	1.3834	0.0000	0.6747	0.0001	1.1984	0.0103

a_1	-0.2713	0.0005	-0.2814	0.0033	-0.3049	0.6014
a_2	0.0640	0.3312	0.0027	0.9742	0.1980	0.7295
a_3	-0.1572	0.0775	-0.4128	0.0307	-1.6333	0.6129
a_4	-0.1900	0.0020	-0.2327	0.0103	0.0950	0.7915

Table 3 - Estimation results: model equation (7)

	Australian		**European**		**USA**	
Coefficient	Value	p-value	Value	p-value	Value	p-value
b_0	1.2620	0.0000	0.5810	0.0000	0.8287	0.0000
b_1	-0.2860	0.0000	-0.1286*	0.0548	-0.0660**	0.5891
b_2	0.0778	0.1130	0.1599	0.0584	-0.0588	0.6104
b_3	-0.1242	0.0353	-0.4655	0.0058	-1.0836	0.2552
b_4	-0.1674	0.0005	-0.4314	0.0000	0.0552	0.6261
b_5	-0.0817	0.0158	0.0692	0.0275	0.0591	0.4735
b_6	0.2556	0.0000	0.3634	0.0000	0.6190	0.0000
b_7	0.1393	0.0001	0.2219	0.0000	0.4742	0.0000
b_8	0.1726	0.0000	0.2114	0.0000	0.2718	0.0013
b_9	0.2764	0.0000	0.2088	0.0000	0.3187	0.0003
b_{10}	-0.1675	0.0000	0.1613	0.0000	0.3212	0.0003

* If we remove the least significant coefficient (b_2), we can reject the hypothesis of b_1 being zero at the 5% significance level.

** If we remove the least significant coefficients (b_2, b_3 b_4 b_5), we can reject the hypothesis of b_1 being zero at the 10% significance level.

In general, our results validate the model predictions in the volatility behavior. It is interesting to note that the values of parameters a_4 and b_4 are also statistically significant in the European and Australian electricity markets. Their negative values show that there seems to be an inverse relationship between the volume of transactions and price volatility. In this way, we can expect a decrease in volatility of electricity prices as the volume of transaction in the spot market increases.

The weekday effect is also important to explain the volatility of electricity prices. We can see that in general parameter b_6 (Monday) is positive and higher than the other weekday coefficients. This shows that we can expect a higher volatility on Mondays than other weekdays.

6. CONCLUSIONS

This paper provides a model of electricity price returns in the context of interconnected markets, based on the idea that interconnection is the best real time arbitrage mechanism between prices in different electricity markets. The model predicts, in general, an inverse relationship between electricity price volatility and the level of interconnection. Therefore, as the capacity of interconnection between markets increases, we can expect a decrease in their joint price volatility.

An empirical analysis in the Australian, European and USA / Canada electricity markets reveals some evidence of an inverse relationship between the interconnection level and the joint volatility of prices. We used the correlation of prices between markets as an indicator of the interconnection level. This is in part a limitation in our empirical research, because other factors – not only the interconnection level – contribute to an increase in correlation. A possible way to overcome this indirect measure for physical interconnection could be the direct measure of the transmission lines and their electricity flows between markets. However, we had no access to this kind of information.

This line of research presents new and exciting problems and is a natural ground for new studies that will help us to understand electricity markets and their price formation. In future works it will be important to examine the impact of other variables on volatility, such as the generation capacity, the generation mix, the regulations and market structures, and other constraints that may impact electricity prices. Another important aspect is the dynamic nature of interconnections and transmission systems in general. In electrical power systems, there is a lot of research about the dynamic safety of the transmission system. The system must sustain some production outages and line failures without collapsing. Therefore, we need to operate the system outside a certain distance from such a point of collapse. This issue may well be extended to future electricity prices research.

8. REFERENCES

Black, F. e M. Scholes, 1973. The price of options and corporate liabilities. Journal of Political Economy 81, No. 1, 637-659.

Carr, P. and L. Wu, 2004. Time-changed Levy processes and option pricing. Journal of Financial Economics 71, No. 1, 113-141.

Carr, P. and L. Wu, 2003. What type of process underlies options? A simple robust test, Journal of Finance 58, No. 6, 2581-2610.

Huisman, R. and R. Mahieu, 2003. Regime jumps in electricity prices. Energy Economics 25, No. 5, 425-434.

Li, Y. and P. C. Flynn, 2004. Deregulated power prices: comparison of diurnal patterns. Energy Policy 32, No. 5, 657-672.

Nogales, F.J., Contreras, J., Conejo, A.J., and Espínola R., 2002. Forecasting next-day electricity prices by time series models. IEEE Transactions on Power Systems 17, No. 2, 342-348.

Appendix

Considering constant prices in (t=0), the joint volatility of price without interconnection is given by (A1).

$$V(R_{p_A}) + V(R_{p_B}) = V(p_A^{t=1}) + V(p_B^{t=1}) \qquad (A1)$$

In the same way (A2) gives the joint volatility of prices with interconnection.

$$\begin{aligned} V(R^*_{p_A}) + V(R^*_{p_B}) = &\left[(1-\alpha)^2 + \beta^2\right]V(p_A^{t=1}) + \left[(1-\beta)^2 + \alpha^2\right]V(p_B^{t=1}) + \\ &2COV\left[(1-\alpha)p_A^{t=1};\alpha p_B^{t=1})\right] + 2COV\left[(1-\beta)p_B^{t=1};\beta p_A^{t=1})\right] \end{aligned} \qquad (A2)$$

If we consider the Cauchy-Schwartz inequality:

$$COV(X;Y) \le V(X)V(Y) \qquad (A3)$$

We can change (A2) into the following inequality:

$$\begin{aligned} V(R^*_{p_A}) + V(R^*_{p_B}) \le &\left[(1-\alpha)^2 + \beta^2\right]V(p_A^{t=1}) + \left[(1-\beta)^2 + \alpha^2\right]V(p_B^{t=1}) + \\ &2\alpha^2(1-\alpha)^2 V(p_A^{t=1})V(p_B^{t=1}) + 2\beta^2(1-\beta)^2 V(p_A^{t=1})V(p_B^{t=1}) \end{aligned} \qquad (A4)$$

Simplifying:

$$\begin{aligned} V(R^*_{p_A}) + V(R^*_{p_B}) \le &\underbrace{\left[(1-\alpha)^2 + \beta^2\right]}_{a}V(p_A^{t=1}) + \underbrace{\left[(1-\beta)^2 + \alpha^2\right]}_{b}V(p_B^{t=1}) + \\ &\underbrace{2\left[\alpha^2(1-\alpha)^2 + \beta^2(1-\beta)^2\right]}_{c}V(p_A^{t=1})V(p_B^{t=1}) \end{aligned} \qquad (A5)$$

If we consider similar volatilities in both electricity markets, i.e. $V(R_{pA}) = V(R_{pB}) = V(R_p)$, then $V(R_{pA}) + V(R_{pB}) = 2\ V(R_p)$. In this case:

$$\begin{aligned} &V(R^*_{p_A}) + V(R^*_{p_B}) \le aV(R_p) + bV(R_p) + 2cV(R_p) \\ \Leftrightarrow\ &V(R^*_{p_A}) + V(R^*_{p_B}) \le (a+b+2c)V(R_p) \end{aligned} \qquad (A6)$$

This result means that just the interconnection can provide a decrease in joint volatility, up to 25%, because (a+b+2c) is in the interval [1.5; 2.0].