The Takayama and Judge Price and Allocation Model and its application in non-linear techniques for spatial market integration

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The Takayama and Judge Allocation models serve as the theoretical foundation for spatial market integration analysis, and despite the large number of papers devoted to the topic, still the knowledge and understanding of the economic phenomena is fragile. By generating artificial economic data under an economic framework, it is expected to contribute to a better understanding of the topic and revise if the current econometric (threshold vector error correction models) techniques are suitable for the analysis or not. Following the static and equilibrium nature of the Takayama and Judge models, it was possible to introduce dynamics and disequilibrium in the model to generate artificial data: prices. Such artificial prices were used to get a first insight on how to address further research.

I. Introduction to the spatial equilibrium condition

To what extent space plays a role in markets performance is a question of interest for economist. Well-functioning markets involves issues such as monetary policy, international trade, exchanges rate and gains distributions among others; and although equilibrium should characterize the markets, there is strong evidence concerning arbitrage opportunities taking place. Spatial distribution plays a major role in the markets performance, for instance consider lack of markets access, if that would be the case isolated firms might neglect the adoption of new technologies (Barret, 2008).

The economic theory concerning markets and space deals with the concept of "Spatial Market Integration", the concept has received much attention, for instance consider authors such as Harris (1979), Ravallion (1986), Goodwin and Schroeder (1991), Roll (1979), Barret (2008), Fackler & Goodwing (2001) and Barret (2008), and although to some extend there is not a unique definition, the core theory behind market integration deals with tradable goods. Assuming excess supply and demand among regions, tradability is the linkage among markets; furthermore prices play a fundamental role by ensuring the optimal allocation of resources under perfect competition. Indeed the economic model that serves to understand "Spatial Market Integration" is the so called Takayama and Judge Price and Allocation Model (TJM) which denotes a partial equilibrium on which two or more regions trade one or more goods subject to linear constrains. For understanding the model consider a single commodity and two separated markets, the equilibrium between the regions is subject to the spatial equilibrium condition denoted as

$$P_i \leq c + P_j \tag{1}$$

being P_i the price of the commodity in region i, P_j the price of the commodity in region j and c the transaction costs of trading product from region j to region i . Equation (1) is known as the Law of the One price (LOP) which guarantees no arbitrage opportunities by binding prices. To understand more in detail the rational behind the the TJM lets consider a single commodity and n regions with linear demand and supply functions

$$y_n = \alpha_n - \beta_n p_n^d \tag{2}$$

$$x_n = \theta_n + \gamma_n p_n^s \tag{3}$$

denoting y_n and x_n the demanded and supply quantity respectively, p_n^d and p_n^s the demand and supply prices, α_n and θ_n the intercept, and β_n and γ_n positive parameters. For both equations, the inverse supply and demand function can be expressed as:

$$p_n^d = \lambda_n - \omega_n y_n \quad (4)$$

$$p_n^s = \nu_n + \eta_n x_n \quad (5),$$

the transport costs from trade can be depicted as a matrix such that:

$$\boldsymbol{T_{ab}} \equiv \begin{bmatrix} 0 & t_{21} \cdots t_{n1} \\ t_{12} & 0 \ \cdots t_{n2} \\ \vdots & \ddots \ 0 \ \vdots \\ t_{1n} & t_{2n} \cdots \ 0 \end{bmatrix} \quad (6)$$

being **T** the transport cost matrix which contains the transport cost *t* of moving a unit of the commodity from region *i* to region *j*, the amounts of trade among regions can be denoted as a matrix of the following form

$$\boldsymbol{Q_{ij}} \equiv \begin{bmatrix} 0 & q_{21} \cdots q_{n1} \\ q_{12} & 0 \ \cdots q_{n2} \\ \vdots & \ddots \ 0 \ \vdots \\ q_{1n} & q_{2n} \cdots \ 0 \end{bmatrix} \quad (7);$$

Takayama and Judge (1964) showed that under the previous assumptions, the consumer surplus has the form

$$CS = (\lambda - \boldsymbol{\Omega} y)' y - (\nu + \boldsymbol{H} x)' x - \boldsymbol{T}' \boldsymbol{Q} \quad (8)$$

with λ denoting a vector containing all the parameters λ_n , ν a vector containing all the parameters ν_n, *y* a vector containing the quantity demanded for each region y_n, *x* a vector containing the quantity supplied on each region x_n, Ω and H matrixes containing the parameters ω and η respectively. Maximizing equation (8) subject to the following constrains

$$\begin{pmatrix} I & & -G_y \\ & -I & -G_x \end{pmatrix} \begin{bmatrix} y \\ x \\ X \end{bmatrix} \leqq 0 \quad (9)$$

$$y \geqq 0, x \geqq 0, \boldsymbol{X} \geqq 0 \quad (10)$$

denoting **I** unitary matrices, and $\mathbf{G_x}$ and $\mathbf{G_y}$ matrices containing ones, leads to a equilibrium. Such equilibrium is characterized with supply and demand prices within a region being equal, and prices among regions bounded as in equation (1); in other words arbitrage opportunities are exhausted within and among the regions.

II. Spatial Equilibrium Condition and Price Transmission Analysis

Although the spatial equilibrium condition or law of the one price (LOP) is necessary to understand spatial market integration, both concepts have a fundamental difference. The LOP can be understood as a static concept rather than an economic phenomena; for instance assuming prices always in equilibrium would be fool in reality. Following Barret (2001) and Barret & Li (2002) it becomes important to stress the difference between a spatial equilibrium such as equation (1) and spatial market integration, where arbitrage opportunities (disequilibrium) might co-exist with the equilibrium condition, as for that it can be possible to rewrite equation (1) in the following way

$$z_t = c + \beta P_{j,t} - P_{i,t} \qquad (11)$$

being β the co-integration parameter, z_t the disequilibrium , and the sub-index t the time dimension; (11) is reduced to (1) when β equals to one and z_t equals zero. Notice that there is a fundamental change as the process now is not static but dynamic.

The study of spatial markets integration is concerned with a series of econometric techniques dealing with time series analyses. Although economic theory, as depicted in the TJM, involves not only prices, but amounts of trades and transaction costs as well, in practice research involves mainly data from prices, as for that the name of Price Transmission Analysis. It has been shown that estimating equation (11) with simple Ordinary Least Squares (OLS) with prices (time series processes) leads to spurious regression as such prices often are found have a unit root (I(1)); this problem was addressed by Engle and Granger (1987) by developing the so called co-integration technique; they showed that if z_t is an stationary process, I(0), the equation (11) can be estimated with OLS; furthermore its has the advantage that contains a dynamic element know as Error Correction Term which is adjusted over the time in the form

$$\Delta p_{i,t} = \alpha_1 z_{t-1} + \sum_{i=1}^{K} \psi_{1,i} \Delta p_{j,t-i} + \sum_{i=1}^{K} \psi_{2,i} \Delta p_{i,t-i} + \varepsilon_{1,t} \qquad (12)$$

$$\Delta p_{j,t} = \alpha_2 z_{t-1} + \sum_{i=1}^{K} \xi_{1,i} \Delta p_{i,t-i} + \sum_{i=1}^{K} \xi_{2,i} \Delta p_{j,t-i} + \varepsilon_{2,t} \qquad (13)$$

denoting α_1 and α_2 the so called loading coefficients. To understand the economic interpretation of the estimated parameters β, α_1 and α_2 in price transmission analysis is necessary to refer to the term market integration not as a specific relation, bur rather as a degree, namely "degree of integration" which can be measured using co-integration analysis (Fackler & Goodwing, 2001; Fackler, P. & Tastan, H., 2008). Following this idea the estimated co-integration vector, β=(-1, β), serves as a measurement of the equilibrium, being a perfect equilibrium (LOP) when β=(-1, 1); as not all the prices lies on the estimated equilibrium, any price below or above it is said to be in a disequilibrium; as for that the loading coefficients α_* is interpreted as the adjusting parameters (speed of adjustment), which denotes how fast prices adjust (increase or decrease) in order to restore the equilibrium. Indeed the force driving back prices back to the equilibrium is arbitrage; on this regard Barret & Li (2002) state that trade is a necessary condition for integration but not for equilibrium. The co-integration method developed by Engle and Granger (1987) assumes that the co-integration vector also called long run relationship, and the loading coefficients are constant (linear); nonetheless such behaviour does not always depict economic in reality. Recall equation (1), it is shown the equilibrium is not a single point as depicted in equation (11) but a rather a range or a band; indeed whiting such band prices should not exhibit adjustment as they are already in equilibrium. Another major pitfall of the linear approach is the assumption of stationary transaction costs, it is easy to argue that such assumption is not realistic as transaction costs depends on energy prices which also have a unit root.

Following the previous concerns the threshold co-integration model developed by Balke and Fomby (1997) has become the standard application in price transmission analysis. Considers the error term z_t being an autoregressive process such as

$$z_t = \rho^{(i)} z_{t-1} + \varepsilon_t \tag{14}$$

where the parameter $\rho^{(i)}$ has a threshold value θ such that

$$\rho^{(i)} = \begin{Bmatrix} \rho^{(1)} \; if \; |z_{t-1}| \leq \theta \\ \rho^{(2)} \; if \; |z_{t-1}| > \theta \end{Bmatrix} \tag{15}$$

The idea of the threshold co-integration can be extended to several models such as Threshold Autoregressive Model (TAR), Smooth Threshold Autoregressive Model (STAR), Bans Threshold Autoregressive Models (BAND-TAR), Equilibrium Threshold Autoregressive Model (EQ-TAR), Self Extracting Threshold Autoregressive Models (SETAR) and the Threshold Vector Error Correction Model (TVECM). For instance the SETAR with two thresholds takes the following form

$$z_t = \left(\alpha_0 + \alpha_1 z_{t-1} + \cdots + \alpha_p z_{p-1}\right) 1(z_{t-1} \leq \theta)$$

$$+\left(\beta_0 + \beta_1 z_{t-1} + \cdots + \beta_p z_{p-1}\right) 1(z_{t-1} > \theta) + e_t \tag{16}$$

while the TVECM has the form

$$\Delta p_t = \begin{Bmatrix} \mu^{(1)} + \gamma^{(1)} z_{t-1} + \sum_{i=1}^{k-1} \psi_i^{(1)} \Delta p_{t-i} + \epsilon_t \; if \; |z_{t-1}| \leq \theta \\ \mu^{(2)} + \gamma^{(2)} z_{t-1} + \sum_{i=1}^{k-1} \psi_i^{(2)} \Delta p_{t-i} + \epsilon_t \; if \; |z_{t-1}| > \theta \end{Bmatrix} \tag{17}$$

The threshold model with two thresholds can be interpreted economically as prices to be in three regions: one representing called the middle band; and two regimes, one above and other below the middle band, representing prices in disequilibrium when profits are possible for some agents (Goodwin, B. & Piggott, 2001; Septon, P., 2003). For such reasons, among others, the family of threshold models has gained popularity and have become the standard application in price transmission analysis, nonetheless there are some challenges such as testing threshold co-integration and estimation of the threshold parameter among others; examples addressing such challenges include Chan (1993), Chien, L. & Zivot, E. (2001), Caner & Hansen (2001), Lo & Zivot (2001), Hansen &

Seo (2002), Kapetanios (2003), Gascoigne (2004), Seo (2005), Gonzalo & Pitarakis (2006), Cook (2007), Balcome & Rapsomanikis (2008) and Ping (2010) among others.

III. Partial Equilibrium and disequilibrium modelling

The concern regarding empirical research on Price transmission deals on how adequate are the current co-integration methods for real data. In an exposure critique, Barret (2008) states that given limited data on transactions costs and volumes, economist have fragile foundations for making strong judgements. Such questioning can be extended not only to the data availability, but to the implementation of techniques used price transmission analysis: why should it be assume a constant exponential adjustment, why to including smooth functions on the estimations. For instance such question can be addressed properly by generating artificial data under an economic model, and then use that data in the current price transmission techniques to revise if the data serves in the estimations, and to compare the estimated parameters versus the original parameters. On this regard Baulch (1994) estimated the bias from the so called Parity Bounds Model by using data with parameters conceived beforehand (data generated artificially); nevertheless he ignores the times series properties of the data. The approach followed by Baulch can be extended to explore how well the TVECM performs with data generated under economic theory. Nevertheless there is a main concern regarding the TJM in price transmission analysis: the static nature of the model which only gives prices in equilibrium, and although Takayama introduced some dynamics regarding transport costs and uncertainty in later work (Takayama, T. & Woodland, A. :1970; Takayama, T. & Judge, G. :1971 and Takayama, T. :1994) for this research it is followed another approach.

Recall that the theory behind price transmission assumes that prices have a unit root, following this idea a useful way to introduce some dynamic on the TJM is to consider the parameter ν in equation (5) to be a random walk process such that

$$\nu_t = \nu_{t-1} + \varepsilon_t = \nu_0 + \sum_{s=1}^{t} \varepsilon_t \quad (18)$$

such equation implies that the prices are time variant processes following a random walk such that

$$p_{n,t}^{s} = \nu_{n,t} + \eta_n x_{n,t} = \nu_0 + \sum_{s=1}^{t} \varepsilon_t + \eta_n x_{n,t} \quad (19)$$

So far prices can be said to have a unit root, nevertheless if the model is solved without additional restrictions, the outcome is prices in the middle band or in equilibrium. As for that the model has to be restricted in order to observe prices outside the middle band. The approach followed is to restrict trade between regions *i* and *j* so as arbitrage opportunities can take place. Let denote x_{ij}^{Eq} the amount of trade in equilibrium, and x_{ij}^{Dis} the trade in disequilibrium, $p_{*,t}^{Eq}$ and $p_{*,t}^{Dis}$ the prices in equilibrium and disequilibrium respectively. The following conditions hold for disequilibrium and equilibrium variables:

$$x_{ij,t}^{Eq} < x_{ij,t}^{Dis} \; then \; p_{i,t}^{Eq} - p_{j,t}^{Eq} > p_{i,t}^{Dis} - p_{j,t}^{Dis} \qquad (20)$$

$$x_{ij}^{Eq} > x_{ij}^{Dis} \; then \; p_{i,t}^{Eq} - p_{j,t}^{Eq} < p_{i,t}^{Dis} - p_{j,t}^{Dis} \qquad (21)$$

The implication of equations (20) and (21) is that the difference in the prices in the disequilibrium will be either above or below the transactions costs. Trade disequilibrium might be imposed by introducing a new constrain such that

$$x_{ij,t} \leq a \qquad (22)$$

with a denoting a random number normally distributed.

IV. Simulating and estimating the models

After setting up a framework on which is possible to solve data under the TJM in a dynamic equilibrium and disequilibrium is possible to proceed to perform some simulations. Consider the following two regions model based on the example provided by Takayama and Judge (1964), the inverse supply functions are denoted as

$$p_{1,t}^{s} = 5 + \sum_{s=1}^{t} \varepsilon_t + 0.1x_{1,t} \qquad (26) \qquad\qquad p_{1,t}^{d} = 20 - 0.1y_{1,t} \qquad (23)$$

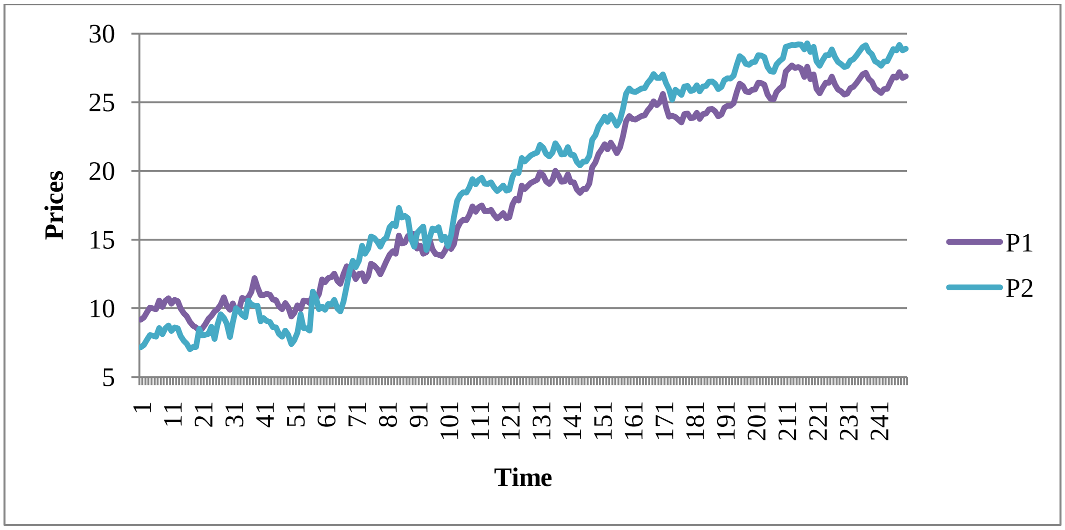
$$p_{2,t}^{s} = 2.5 + \sum_{s=1}^{t} \varepsilon_t + 0.05x_{2,t} \qquad (28) \qquad\qquad p_{2,t}^{d} = 20 - 0.2y_{2,t} \qquad (24)$$

with $\varepsilon \backsim N(0,1)$ and a matrix of transport costs

$$t_{12} = \begin{bmatrix} 0 & 2 \\ 2 & 0 \end{bmatrix} \qquad (25)$$

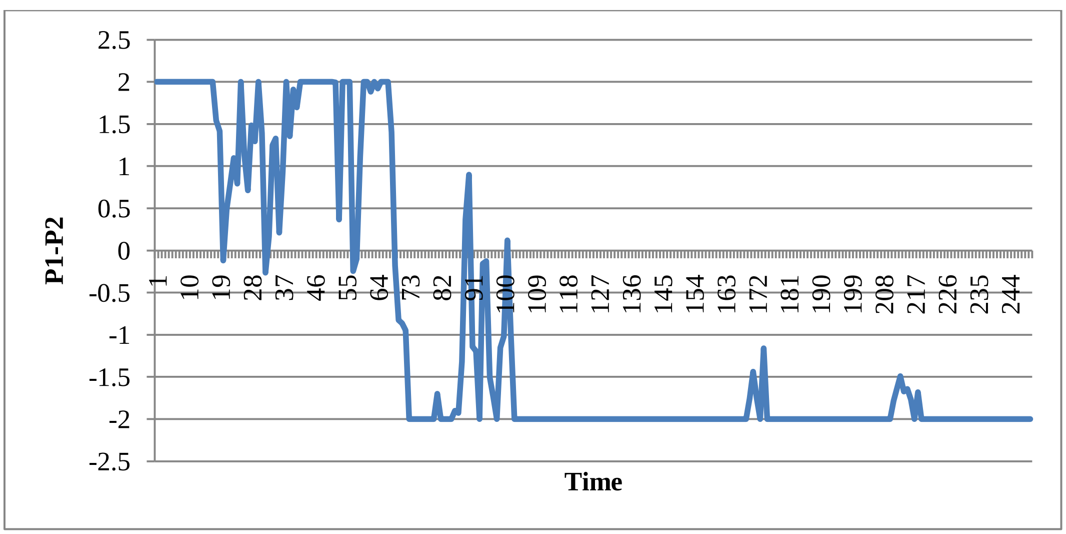
Notice that the previous model assumes a dynamic equilibrium. Regarding the parameters conceived beforehand the co-integration vector, although not specified, is **β**=(-1, 1) because the TJM solves for the spatial equilibrium condition. Furthermore recall that the prices are bounded by the transaction costs, as for that the thresholds values for a three-regime threshold model are θ=2 and θ=-2. The previous model can be easily implemented and solved in GAMS; for starting one hundred simulations each one with 250 observations (time periods) were performed for the above model. It can be seen that introducing a random walk leads to trade reversals (Graphic 1)

Graphic 1. Simulated prices in equilibrium with a random walk



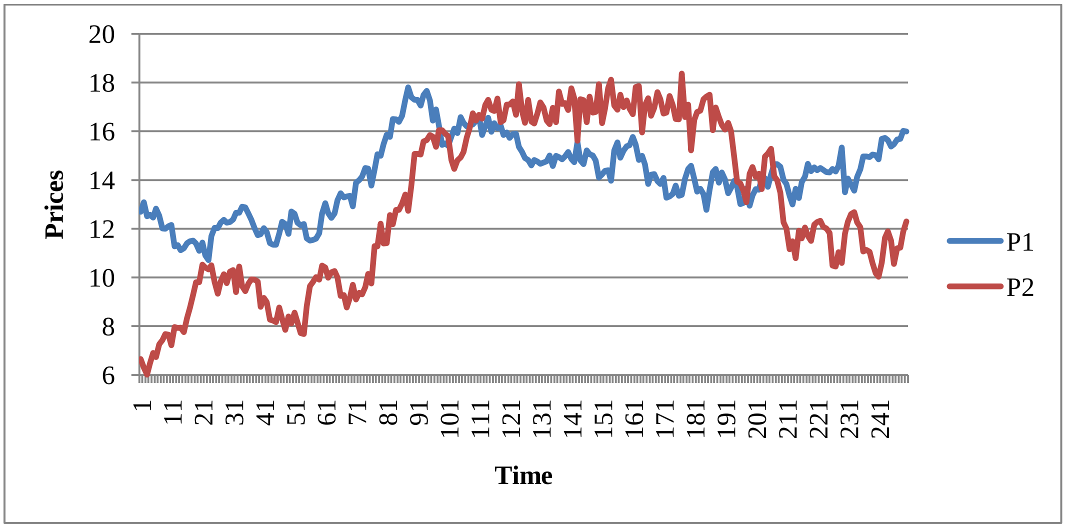
The difference between the prices lays always in the so called middle band as seen in Graphic 2; that is the perfect fulfilment of the spatial equilibrium condition. As stated by Barret & Li (2002) notice that trade is a necessary condition for integration but not for equilibrium: when the prices difference is equal to zero, the amount of trade between regions is zero and prices are in equilibrium.

Graphic 2. Difference between prices for region one and two in equilibrium



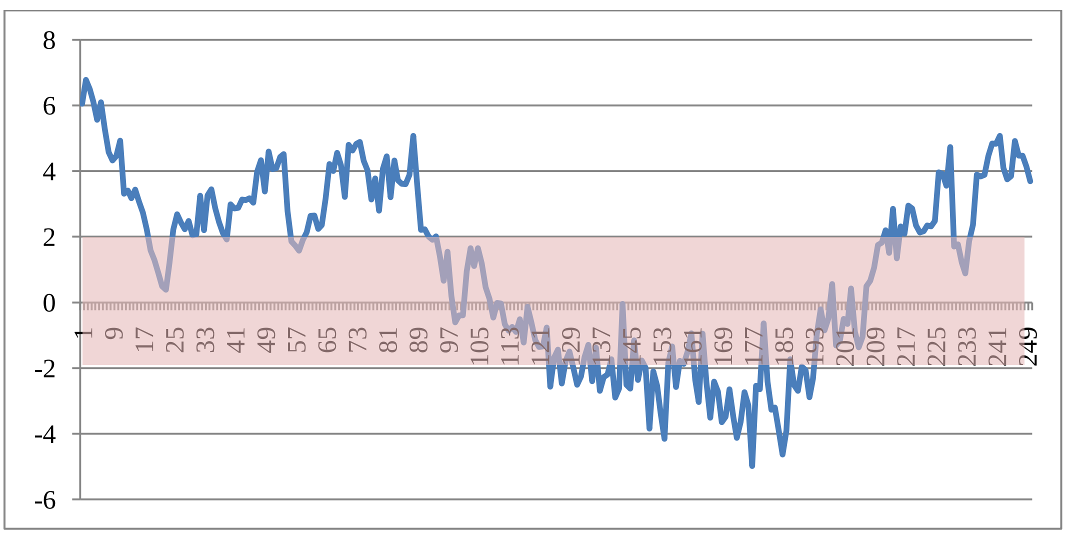
The following step on the simulations is to generate data under disequilibrium conditions. The disequilibrium was introduced by imposing the following trade constrains $x_{12,t} \leq a$ and $x_{12,t} \leq b$, with $a \backsim N(25, 2.5)$ and $b \backsim N(60, 6)$; as in the equilibrium case the disequilibrium was simulated 100 times each one with 250 observations. Notice that the co-integration vector and the threshold values do not change as those from the equilibrium data. The outcome is that prices exhibit again a random walk process with trade reversals and no trade (Graphic 3), nonetheless for some period prices do not follow the same pattern and drift apart.

Graphic 3. Simulated prices in disequilibrium with a random walk



It can be appreciated that prices differences between regions go outside the middle band (Graphic 4)

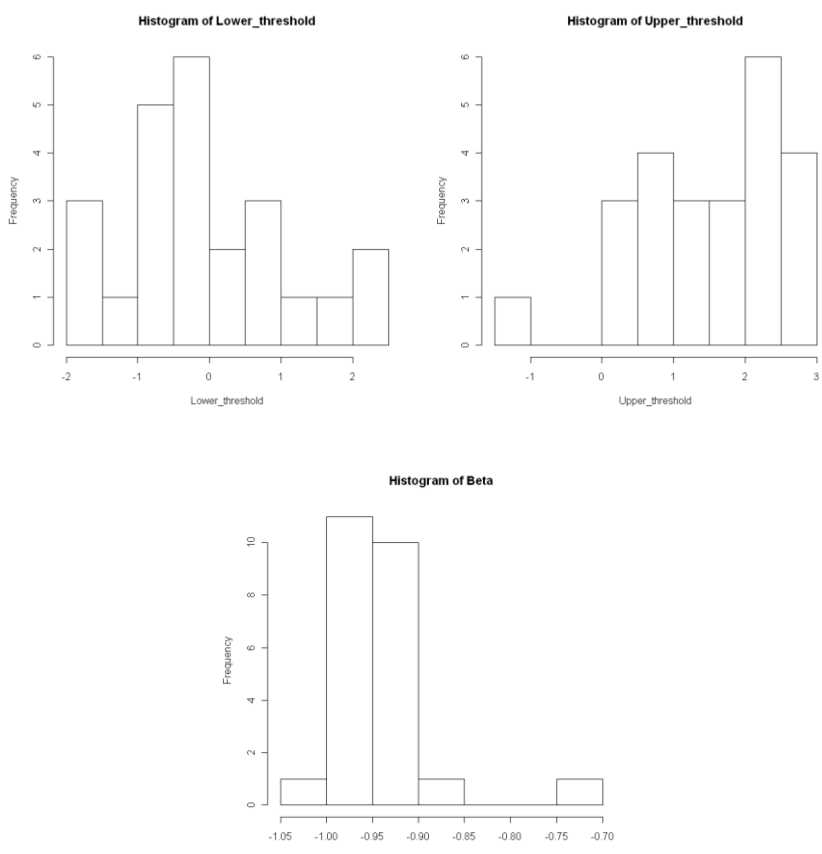
Graphic 4. Difference between prices for region one and two in disequilibrium



Once the TJM have been solved for equilibrium and disequilibrium, it is possible to use the prices obtained to estimate TVECM with three regimes, in order to compare the conceived beforehand parameters with the estimated parameters from the TVECM. The basis for selecting a three regimes model is the presence of trade reversals.

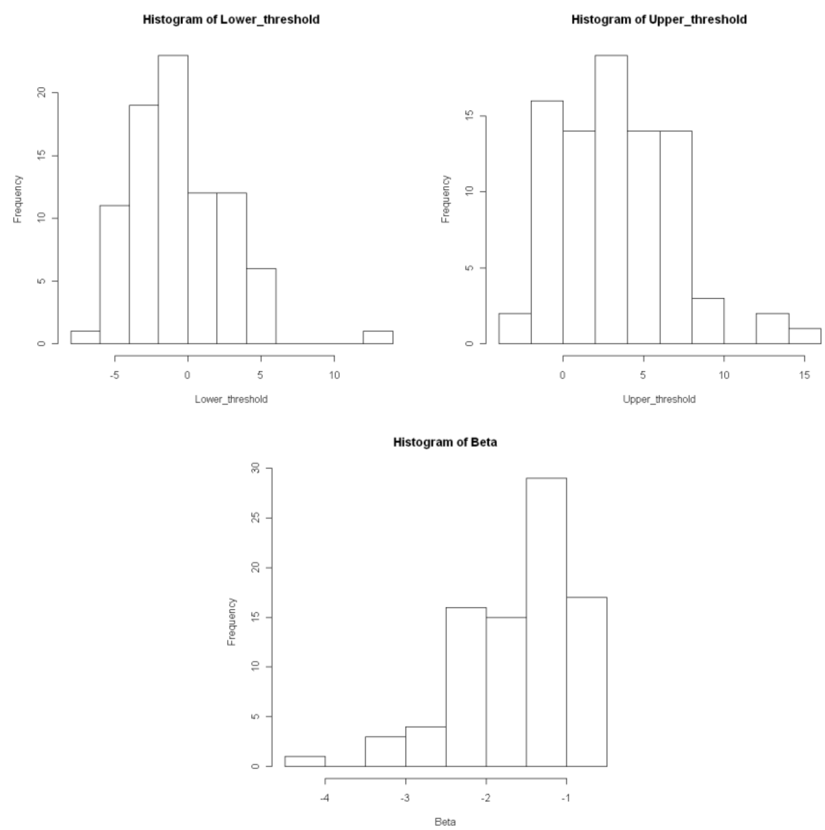
Regarding the prices in equilibrium, recall that the threshold estimation relies on the presumption that real prices are not in equilibrium, on this regard disequilibrium data is necessary in order to estimate properly the threshold, this makes that the model with data in equilibrium to be miss specified. The artificial prices (simulations) assuming equilibrium conditions are used to estimate 100 threshold models (TVECM) with two thresholds; the estimation was done using the R package tsDyn developed by Di Narzo et.al. (2009). The results suggest that only 25 out of 100 TVECM are possible to estimate, the main reason for this outcome is prices variation in equilibrium is quite low, most of the time prices are not even within the band but on its limits. The average value for the lower threshold denoted as $\widehat{\theta_1}$ equals -0.05, while the average value for the upper threshold denoted as $\widehat{\theta_2}$ is 1.44. Indeed the estimation of the threshold is based on the long run relationship or co-integration estimated vector $\hat{\beta}$ which average is -0.94. The histograms of the three estimated parameters are depicted in the graphic below

Graphic 5. Histograms of the average estimated thresholds and co-integration vector in equilibrium



Following the estimation of the TVECM in the equilibrium, the same procedure is performed with the disequilibrium prices. As expected, prices in disequilibrium go outside the middle band (stronger fluctuation), on this regard data might be more suitable for estimating the TVECM and furthermore the model is not miss specified; nevertheless the estimation might be biased if most of the prices are far away from the equilibrium. It is possible to estimate 86 models out of 100 possible as prices fluctuate more, nonetheless still is not possible to say if such estimation is accurate. The average of the estimated parameters for the lower threshold, upper threshold and co-integration vector are -0.72, 3.35, and -1.57 respectively; their distributions can be seen on the graphic below.

Graphic 6. Histograms of the estimated differences between estimated and real values thresholds and co-integration vector in disequilibrium



V. Analysis of results and conclusions

The simulations performed that prices between regions are always within the middle band or equilibrium region, which is (-2, 2). Furthermore in most of the cases, prices are laying in the boundaries of the band; therefore prices are not so disperse. The force driving prices towards the centre of the middle band is trade reversals. Trade reversals occur when random walks in the inverse supply function shift a supply region to a demand region and vice versa, such issues might deserve more attention. Recall that the estimation of the co-integration vector *(1,-β)* assumes a normalization of one of the vector prices; although in economics the normalization is based on econometrics arguments such as causality tests, some arguments are more based on the direction of trade and the amount of trade. In the presence of trade reversals occurring quite often, making a decision on the prices to normalize might not be quite straight forward.

Regarding the estimation process, recall that the TVECM with price data in equilibrium is miss specified, the outcome of the estimation suggest that some differences between true and estimated parameters. The average estimated co-integration vector is β =(1, -0.94), that is a slight downwards deviation from the spatial equilibrium condition (1,-1). For the middle band estimation, that is the upper and lower threshold values, the average values are in the range (-0.05, 1.44) that is a smaller range if compared with the true band (-2, 2). One would expect that the deviation of the co-integration vector to affect the threshold estimation as well on the same direction, nevertheless the results do not suggest such outcome. An important issue to stress is the fact that it was possible to estimate only 25 replications out of 100; at a first glance one might assume that the reason for this is the miss specification by only using data in equilibrium, nevertheless that argument is debatable. The Hansen and Seo approach is based on maximum likelihood estimation and a grid search for both, the co-integration vector and the threshold parameters; nonetheless the calibration of the grid search is based on the consisted estimator of the co-integration vector from a regular VECM, which is an OLS regression. If most of the time prices are in the boundaries of the band, as it has been discussed, it not a surprise that the OLS estimation will fail because the matrix becomes singular. On this regard and in order to support the argument that the miss specification is the main cause for which is not possible to estimate the model, more replication are needed; furthermore more attention shall be paid on the trade reversals as they are the solely source of prices dispersion within the equilibrium band. At this point is important to stress again the issue of normalization, for a matter of simplicity prices in region 2 are set up as the "exogenous" price for all the estimations, nonetheless whether or not the previous outcomes will hold if the estimations are done by normalizing prices for region one need to be revised.

For the disequilibrium simulations the restriction plays a majors role. For instance consider that the random walk leads to an explosive increase in the trade for one direction, as the restriction is a random number normally distributed with each time period independent, then it is quite easy that at some point the restriction will be too restrictive and prices will drift apart dramatically and far away from the equilibrium middle band. As for this the price dispersion won't be bounded to the middle band, and prices have more variation if compared with the equilibrium situation. As argued before the variation is important in order to estimate the OLS regression, the results suggest that data in disequilibrium is more adequate for the estimation process as 86 out of 100 threshold models are possible to estimate. It is important to recall that the source of variation is not only the trade restriction, but trade reversals as well. As for the true parameters versus the estimated ones the co-integration average estimated co-integration vector is (1,-1.56), that is a deviation upwards the true value (1,-1), concerning the deviation on the average estimated middle band, (-0.72, 3.35), it goes on the same direction as it was expected. The issue of normalization as before still is a matter to be revised more in detail.

The simulations performed provided some hints on which direction future research should go and which questions need to be addressed in order to asses how suitable are the TVECM for estimating parameters with real data, namely prices. For instance the first issue is to control for the random walk in order to avoid such an explosive behaviour on the prices, a plausible solution would be to think on the parameter ν_t not as a purely random walk, but as a process with two components: a unit root and a stationary part, on this way the stationary component might help to control the explosive behaviour. Once the explosive behaviour is more or less controlled, another issue is how to set up the trade restriction, a purely random number might become too restrictive for some cases, as for that a sort of dynamics on it might be more useful, for instance a moving average process explained by contemporaneous and past shocks. Following this approach might offer a better foundation from the economic perspective as shocks can be seen as the cause of disequilibria and arbitrage opportunities.

Recalling Barret (2008), the research should pay more attention in the econometric properties of the data. So far this research have neglected many of this properties as well, so formal testing of a unit root on the prices, testing threshold co-integration, and revising if the TVECM estimation is converging are issues that need to be revised more in detail. On this field there is a lot of scope for improvement on this research. Although it has to be taken with reserves, the outcome of this research suggests that the miss specified model does not fit into the TVECM estimation, not only because the low numbers of simulations that are viable, but also because the middle band estimation is shrunk when compared with the true equilibrium region. On this regard it seems interesting to analyse further miss specifications, for instance one can drop price data with no trade reversals into a three regimes threshold model, and vice versa.

The results obtained from this simple exercise serve a starting point in order to understand better not only the economic theory behind the spatial market integration, but to make use of other data than prices in the analysis (trade and transaction costs) and see to what extent the lack of such information in real data might weaken current assumptions or presumptions.

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