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# Genetic structure, consanguineous marriages and economic development: Panel cointegration and panel cointegration neural network analyses ☆

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ABSTRACT

Consanguineous marriages and their effects on human beings in light of biological effects of genetic sicknesses are discussed in many studies. Among many, the likelihood of sicknesses such as phenylketonuria, thalassemia, Landsteiner–Fanconi–Anderson's syndrome, hemophilia and many neuro system anomalies increase drastically in countries with consanguineous marriage practices resulting in increasing economic costs. In the study, we aimed to analyze the effects of consanguineous marriage and its effect on economic growth and development. We also analyzed infant mortality in these countries in light of consanguineous marriages and economic development. In the study, Panel Cointegration specifications are integrated into Neural Network models known with their strong generalization properties. The study focuses the econometric analyses, where the Panel Cointegration Neural Network Model is investigated and compared to the Panel Cointegration Model. According to MSE, MAE and RMSE error criteria and Diebold Mariano tests of equal forecast accuracy, the results suggest strong advantages of Panel Cointegration MLP models compared to Panel Cointegration models used in regression analysis.


## 1. Introduction

We will investigate the effects of consanguine marriage and genetic structure on economic growth and development. The study has two objectives. These are, to look at economic development from a different framework and to collate the Panel Cointegration and neural network literature around the axis of cointegration. The first part contains the econometric theory, where the Panel Cointegration MLP Model is investigated and compared to the Panel Cointegration Model. In the study, as panel structure is merged with neural network structure, the panel cointegration structure is aimed to be augmented with the neural network. Multi Layer Perceptron (MLP) are combined with panel structure and the peformances of the discussed models, Panel Cointegration MLP Model (PCNN) will be obtained to be compared with Panel Johansen Cointegration Model. The second part of the study focuses on economic development and growth, consanguine marriages, infant mortality and genetic structure relations in theoretical framework.

## 2. Econometric theory

### 2.1. Panel unit root

Panel unit root tests have many applications in economics. Further, unit root tests developed for time series is extended to panel models. Assume that time series $\{y_{i0}, y_{i1}, \ldots, y_{iT}\}$ on the cross section units $i = 1,2,\ldots,N$ obtained for each $i$ by an autoregressive process of order 1, AR (1) is stated as

$$y_{it} = (1-\alpha_i)\mu_i + \alpha_i y_{i,t-1} + \varepsilon_{it}, \tag{1}$$

where, the error terms $\varepsilon_{it}$ are identically, independently distributed (*iid*) across $i$ cross sections and $t$ time dimensions with $E(\varepsilon_{it}) = 0$, $E(\varepsilon_{it}^2) = \delta_i^2 < \infty$ and $E(\varepsilon_{it}^4) < \infty$ conditions. Eq. (1) could also be written as deviations from the mean, $\tilde{y}_{it} = y_{it} - \mu_i$. The Dickey–Fuller regression to test unit root is written as

$$\tilde{y}_{it} = \alpha_i \tilde{y}_{i,t-1} + \varepsilon_{it}, \tag{2a}$$

further, if trend variable $t$ is introduced, the Panel Cointegration to be estimated is extended to:

$$\Delta\tilde{y}_{it} = \phi_i \tilde{y}_{i,t-1} + \delta_i t + \varepsilon_{it}. \tag{2b}$$

In the homogeneous version of the test – the autoregressive parameters is identical in all cross section units – the null hypothesis that all time series follow random walk

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$$H_0 : \phi_1 = \phi_2 = \cdots = \phi_N = 0 \tag{3}$$

is tested against the alternative of stationarity

$$H_1 : \phi < 0, \quad \phi_1 = \phi_2 = \cdots = \phi_N = \phi. \tag{4}$$

Conveniently, the alternative hypothesis is altered to allow heterogeneity

$$H_1' : \phi_1 < 0, \quad \phi_2 < 0, \ldots, \phi_{N_0} < 0, \quad N_0 \leqslant N. \tag{5}$$

So that, in the heterogeneous version of the alternative hypothesis, the panel members are stationary with unit specific autoregressive coefficients (Breitung & Pesaran, 2005; Im et al., 2003).

The popular panel unit root test commonly applied in econometric literature are the Levin–Lin (1992, 1993, called LL after) and Levin–Lin–Chu (2002, called LLC after) panel unit root tests, which allow for fixed effects and unit specific time trends in addition to common time trends. Tests are based on analysis of the equation

$$\Delta y_{ic,t} = \alpha_i + \delta_i t + \theta_t \rho_i y_{i,t-1} + u_{it}, \quad i = 1, \ldots, N; \; t = 1, \ldots, T. \tag{6}$$

In their model, allowing for two-way fixed effects, the unit-specific fixed effects are an important source of heterogeneity. The coefficient of the lagged dependent variable is restricted to be homogeneous across all units of the panel. The test may be evaluated as a pooled DF or ADF, potentially with differing lag lengths across the units of the panel and they use ADF tests to test for unit roots. $t$-Statistic is calculated as follows:

$$t_\rho = \frac{(\hat{\rho} - 1)\sqrt{\sum_{i=1}^{N}\sum_{t=1}^{T}\tilde{y}_{i,t-1}^2}}{\frac{1}{NT}\sum_{i=1}^{N}\sum_{t=1}^{T}\tilde{u}_{it}^2}, \tag{7}$$

where

$$s_e^2 = \frac{1}{NT}\sum_{i=1}^{N}\sum_{t=1}^{T}\tilde{u}_{it}^2. \tag{8}$$

The Im–Pesaran–Shin (1997, called IPS after) development LL's framework by following for heterogeneity of the coefficient on the lagged dependent variable (Bildirici, 2004). IPS propose the use of a group-mean bar statistic, where the statistics from each ADF test are averaged across the panel; adjustment factors are needed to translate the distribution of the bar into a standard normal variable under the null hypothesis and show that the $t$-bar statistic converges to a standard normal distribution. The approach followed by IPS in this context is the standard ADF-test in a panel structure

$$\Delta y_{i,t} = \mu_i + \beta_i t + \rho_i y_{i,t-1} + \sum_{j=1}^{p}\phi_{ij}\Delta y_{i,t-j} + \varepsilon_{i,t}, \tag{9}$$

where $y_{it}$ stands for each of the variables presented. Instead of pooling and assuming that $\rho_i$ is the same for all $N$, the IPS methodology uses separate unit root tests for the $N$. The IPS $t$-bar statistic is calculated as the average of the individual ADF statistics

$$\bar{t} = \frac{1}{N}\sum_{i=1}^{N} t_{\rho_i}, \tag{10}$$

whereas, this statistic assumes no cross-country correlation among the errors, $T$ to be the same for all countries and the normalized statistic converges to standard normal in distribution (Bildirici, 2004).

### 2.2. Johansen panel cointegration

Cointegration analysis, introduced by Granger (1981, 1983) and developed further by Engle and Granger (1987), Phillips (1988, 1990), Johansen (1988) and Johansen and Juselius (1990, 1991) has important applications in economics. In the study, we will focus on panel cointegration based on Johansen (1990, 1991) cointegration methodology. Johansen (1988) extended the Granger representation theorem to Johansen–Granger Representation theorem and developed cointegration tests based on likelihood ratio tests in Vector Autoregressive models (VAR) and reduced rank regression analysis developed by Velu, Reinsel and Wichern (1986), Ahn and Reinsel (1990). The integrated regressors studied by Phillips (1988), Phillips and Park (1988) and Sims, Stock, and Watson (1990) have similar statistical properties as of Johansen (1988). Johansen (1991) included the methods to counter for seasonal and constant terms.

Granger representation theorem states the existence of an error correction representation of $X_t$ under the assumptions that $\Delta X_t$ and $\beta' X_t$ have stationary and invertible VARMA representations, for some matrix $\beta'$ (Engle & Granger, 1987; Hansen, 2000). Johansen (1991) theorem suggests that a vector autoregressive (VAR) process $A(L)X_t = \varepsilon_t$, following an $I(1)$ process, has the representation $X_t = C\sum_{i=1}^{t}\varepsilon_i + C(L)\varepsilon_t + A_0$. Accordingly, $\{C(L)\varepsilon_t\}$ is stationary if $\varepsilon_t$ is stationary, where $A_0$ depends on initial values of $X_{t-k}$ such that $\Delta X_t$ and $\beta' X_t$ are stationary, whereas $X_t$ is nonstationary (Johansen, 1991; 1559).

Consider a general VAR model with Gaussian errors

$$X_t = \prod_1 X_{t-1} + \prod_2 X_{t-2} + \cdots + \prod_k X_{t-k} + D_t + \varepsilon_t, \quad t = 1, \ldots, T. \tag{11}$$

As shown by Johansen (1991), if the process is written in error correction form, equation becomes

$$\Delta X_t = \sum_{i=1}^{k-1}\Gamma_i \Delta X_{t-i} + \Pi X_{t-k} + \theta D_t + \mu + \varepsilon_t, \quad t = 1, \ldots, T. \tag{12}$$

Here, $\varepsilon_t$ ($t = 1, \ldots, T$) are independent $p$-dimensional Gaussian variables with mean zero and variance matrix $\Lambda$. $D_t$ are defined as deterministic components such defined as seasonal dummies orthogonal to the constant term, $\Pi = -I + \sum_{i=1}^{k}\Pi_i$ and $\Gamma_i = -\sum_{j=i+1}^{k}\Pi_i$, where $\Gamma_i$, $\theta$, $\mu$ and $\Lambda$ are assumed to vary without restrictions. In order to show that $X_t \sim I(1)$ integrated of order 1, the assumptions are;

- (i) $\det(A(z)) = \det(I - \Pi_1 z - \Pi_1 z^2 - \cdots - \Pi_k z^k)$ are either outside the unit circle or equal to 1, which guarantees that the process is not explosive;
- (ii) $\Pi$ matrix has reduced rank, $r < p$, and can be presented as the product $\Pi = \alpha\beta'$; therefore, there are at least $p - r$ unit roots which leads to cointegration if $r \geqslant 1$;
- (iii) $\alpha'\Gamma\beta'$ matrix has full rank, where $\alpha'$ and $\beta'$ are orthogonal complements to $\alpha$ and $\beta$, so that the process is restricted to the order of integration of 1.

If the model in (13) is denoted as $H_1$, by applying restrictions on $\Pi$, the hypothesis to test (at most) $r$ cointegration vectors, $H_2 : \Pi = \alpha\beta'$ is obtained. $\beta$ and $\alpha$ are $p \times r$ matrices which denote the cointegrating vectors and adjustment coefficients, respectively (Johansen, 1991).

Extending the VAR model in Eq. (13), for a panel data set with $N$ cross sections and $T$ time periods, a panel VAR is written as

$$X_{it} = \sum_{k=1}^{k_i}\Pi_{ik}X_{i,t-k} + \varepsilon_{it} \tag{13}$$

with $i = 1,2,\ldots,N$ groups and $t = 1,2,\ldots,T$ time periods and $j = 1,2,\ldots,p$ variables and the errors are independent identically distributed $\varepsilon_{it} \sim N_p(0,\Omega_i)$. Error representation of the VAR model following Engle and Granger (1987) and Johansen (1991) is

$$\Delta X_{it} = \Pi_i X_{i,t-1} + \sum_{k=1}^{k_{i-1}}\Gamma_{ik}\Delta X_{i,t-k} + \varepsilon_{it}, \tag{14}$$