Research Report: Dynamic Panel Analysis of Interactions and Interdependencies

End of Award Report

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March 30, 2007

1 Background

A number of different approaches have been advanced for the analysis of cross section dependence. In the case of spatial problems where a natural immutable distance measure is available the dependence is captured through "spatial lags" using techniques familiar from the time series literature. In economic applications spatial techniques are often adapted using alternative measures of "economic distance". See, for example, Lee and Pesaran (1993), Conley and Topa (2002), Conley and Dupor (2003), and Pesaran, Schuermann and Weiner (2004), as well as the literature on spatial econometrics surveyed, for example, by Anselin (2001). In the case of panel data models where the cross section dimension (N) is small (typically $N < 10$) and the time series dimension (T) is large the standard approach is to treat the equations from the different cross section units as a system of seemingly unrelated regression equations (SURE) and then estimate the system by the Generalized Least Squares (GLS) techniques. This approach allows for general (time-invariant) correlation patterns across the errors in the different cross section equations.

There are also a number of contributions in the literature that allow for time-varying individual effects in the case of panels with homogeneous slopes where T is fixed as $N \to \infty$. For example, see Holtz-Eakin, Newey and Rosen (1988), and Ahn, Lee and Schmidt (2001), that build on the earlier contributions of Kiefer (1980) and Lee (1991).

In what follows we provide a brief overview of the research conducted on the project. A more complete description of the work is provided in the referenced papers and can be accessed. The core idea and the (econometric) methodology are described in the Method section below.

2 Objectives

The original objective of the project were stated as:

1. To extend the dynamic analysis of panels to take account of interaction effects through measures of economic distance.

2. To establish the importance of (hidden) cross sectional dependence thorough re-ordering.

3. To re-examine the PPP hypothesis using a panel VAR framework, paying particular attention to dynamic heterogeneities and cross section dependencies across countries.

4. To re-examine in a panel VAR framework the relationship between US and UK growth rates in a cross section of individual firms and aggregate shocks.

5. To address neglected issues of heterogeneity and simultaneity in the literature on international growth rates by the use of a panel VECM framework.

The first objective has been achieved in a number of ways involving techniques that use cross sectional averages to sweep up common factors such as spatial dependence. The second objective proved to be a dead end and was discontinued. The third objective is addressed in Pesaran, Smith, Yamagata and Hvozdyk (2006). The fourth objective was superseded by a study of house prices at the State level in the US which provided us with a balanced panel. To handle firm level data further theoretical and numerical work is needed to establish critical values for unbalanced panels. The 5th objective has been addressed in Pesaran, Schuermann and Weiner (2004), Dees, Di Mauro, Pesaran and Smith (2007) and Dees, Holly, Pesaran and Smith (2007). Part of this research has also been funded by the European Central Bank.

3 Methods

Two main methodological innovations have been produced by this research project. Both approach the problem of cross sectional dependence induced by common, unobservable factors, but from different perspectives. First, following the standard common factor approach Pesaran (2006) considers a multifactor error structure model where these factors are proxied by cross sectional averages. The estimation procedure filters the individual specific regressors by means of cross section averages such that asymptotically (as $N \to \infty$) the differential effects of unobserved common factors are eliminated. This is in contrast with the various approaches adopted in the literature that focus on estimation of factor loadings as an input into the GLS algorithm. The estimation approach has the added advantage that it can be computed by ordinary least squares (OLS) applied to an auxiliary regression where the observed regressors are augmented by cross section (weighted) averages of the dependent variable and the individual specific regressors. The approach does not require knowledge of the factor structure and can accommodate general time series patterns in the individual-specific disturbances. This is referred to as a common correlated effects (CCE) procedure, to highlight the fact that the unobserved factors are allowed to be correlated with the included regressors.

The second strand proposes a pair-wise approach which is invariant to the choice of the reference cross section unit as well as to the presence of common factors and heterogeneity (Pesaran, 2007a). Under this approach the pair-wise differences across the cross section units are considered, which eliminate common effects and in general result in reduced persistence. For example, in the case of the output convergence hypothesis the pair-wise differences of log per capita outputs will be stationary irrespective of whether the individual output series are trend stationary or first difference stationary. Given data on $N + 1$ cross section unit, $i, j = 0, 1, 2, ..., N$, a variety of tests can be applied to all possible $N(N + 1)/2$ pairs, and the fraction of pair-wise differences that are stationary can be estimated consistently.

These two novel econometric methods have been developed and applied in several directions, including panel unit root tests, testing for output convergence, purchasing parity hypothesis, determination of real house prices and Global VAR macroeconomic modelling.

4 Results

4.1 Common Correlated Effects Estimators

As noted above one of the core econometric methods which provide consistent estimation and valid inference in large heterogeneous panels under cross section dependence is provided in Pesaran (2006). This work has been further extended by Kapetanios and Pesaran (2007), Kapetanios, Pesaran and Yamagata (2006). Kapetanios and Pesaran (2007) compare the finite sample performance of CCE estimators and factor augmented estimators, and found that the former dominates the latter under almost all designs they considered. Kapetanios, Pesaran and Yamagata (2006) provide asymptotic justification for the CCE estimators with non-stationary multiple factors. Also the CCE approach is applied to panel unit root tests in Pesaran (2007b).

Kapetanios and Pesaran (2007) consider alternative approaches to the analysis of large panel data models in the presence of error cross section dependence. A popular method for modelling such dependence uses a factor error structure. Such models raise new problems for estimation and inference. This paper compares two alternative methods for carrying out estimation and inference in panels with a multifactor error structure. One uses the correlated common effects estimator that proxies the unobserved factors by cross section averages of the observed variables as suggested by Pesaran, and the other uses principal components following the work of Stock and Watson. Their paper develops the principal component method and provides small sample evidence on the comparative properties of these estimators by means of

extensive Monte Carlo experiments. An empirical application to company returns provides an illustration of the alternative estimation procedures.

Kapetanios, Pesaran and Yamagata (2006) examine the important case where the unobserved common factors follow unit root processes and could be cointegrated. It is found that the presence of unit roots does not affect most theoretical results in Pesaran (2006) which continue to hold irrespective of the integration and the cointegration properties of the unobserved factors. This finding is further supported for small samples via an extensive Monte Carlo study. In particular, the results of the Monte Carlo study suggest that the cross-sectional average based method is robust to a wide variety of data generation processes and has lower biases than all of the alternative estimation methods considered in the paper.

A number of panel unit root tests that allow for cross section dependence have been proposed in the literature that use orthogonalization type procedures to asymptotically eliminate the cross dependence of the series before standard panel unit root tests are applied to the transformed series. In Pesaran (2007b) a simple alternative has been proposed where the standard ADF regressions are augmented with the cross section averages of lagged levels and first-differences of the individual series. New asymptotic results have been obtained both for the individual CADF statistics, and their simple averages. It is shown that the individual CADF statistics are asymptotically similar and do not depend on the factor loadings. The limit distribution of the average CADF statistic is shown to exist and its critical values are tabulated. Small sample properties of the proposed test are investigated by Monte Carlo experiments. The proposed test is applied to a panel of 17 OECD real exchange rate series as well as to log real earnings of households in the PSID data.

4.2 Pair-wise Approach

4.2.1 Output convergence

As noted above, Pesaran (2007a) has proposed a pair-wise approach to testing for output convergence that considers all $N(N-1)/2$ possible pairs of log per capita output gaps across N economies. A general probabilistic definition of output convergence is also proposed, which suggests that all such output gap pairs must be stationary with a constant mean. The approach is compatible with individual output series having unit roots, or other non-stationary common components and does not involve the choice of a reference country in computation of output gaps. It is also applicable when N is large relative to T (the time dimension of the panel). After providing some encouraging Monte Carlo evidence on the small sample properties of the pair-wise test, the test is applied to output series in the Penn World Tables over 1960-2000. Overall, the results do not support output convergence, and suggest that the findings of convergence clubs in the literature might be spurious. However, significant evidence of growth convergence is found, a result which is reasonably robust to the choice of the sample period and country groupings. Non-convergence of log per capita outputs combined with growth convergence suggests that while common technological progress seems to have been diffusing reasonably widely across economies, there are nevertheless important country-specific factors that render output gaps highly persistent, such that we can not be sure that the probability for the output gaps to lie within a fixed range will be non-zero.

4.2.2 Purchasing power parity hypothesis

Pesaran, Smith, Yamagata and Hvozdyk (2006) apply the pair-wise approach to testing for purchasing power parity, PPP, which is robust to base country effects, cross-section dependence, and heterogeneity. Given data on $N+1$ countries, $i, j = 0, 1, 2, ..., N$, the standard procedure is to apply unit root or stationarity tests to N relative prices against a base country, 0, e.g. the US. The evidence is that such tests are sensitive to the choice of base country. In addition,

the analysis is subject to a high degree of cross section dependence which is difficult to deal with particularly when N is large. Three ADF type tests, which have the null hypothesis of no adjustment and the alternative of linear adjustment, and the Kapetanios, Shin and Snell (2003) test which has the null of no adjustment and the alternative of non-linear adjustment, are considered. These four tests are applied to quarterly cross real exchange rates for 50 countries over the period 1957Q1-2001Q4. The pair-wise approach clearly shows that the null of no adjustment to PPP is rejected in cases where there are sufficiently large disequilibria so that the real rate is outside the 'band of inaction' set by trade-related costs. When there are such disequilibria and the variance of the change in the real rate is large, it is shown that one can reject the null of no adjustment to PPP up to 90% of the time as compared to around 40% in the whole sample using a linear alternative and almost 60% using a non-linear alternative.

4.3 Testing for Slope Homogeneity in Large Panels

Pesaran and Yamagata (2007) have proposed a standardized version of Swamy's (1970) test of slope homogeneity for panel data models where the cross section dimension (N) could be large relative to the time series dimension (T). The proposed test, denoted by $\tilde{\Delta}$, exploits the cross section dispersion of individual slopes weighted by their relative precision. In the case of models with strictly exogenous regressors, but with non-normally distributed errors, the test is shown to have a standard normal distribution as N and T go to infinity such that $\sqrt{N}/T^2 \to 0$. When the errors are normally distributed, a mean-variance bias adjusted version of the test is shown to be normally distributed irrespective of the relative expansion rates of N and T. The test is also applied to stationary dynamic models, and shown to be valid asymptotically so long as $N/T \to \kappa$, as N and T go to infinity, where $0 \leq \kappa < \infty$. Using Monte Carlo experiments, it is shown that the test has the correct size and satisfactory power in panels with strictly exogenous regressors for various combinations of N and T. Similar results are also obtained for dynamic panels, but only if the autoregressive coefficient is not too close to unity and so long as $T \geq N$. A further research that extends this work to the panel models under cross section dependence is currently under consideration.

4.4 Testing for Cross Section Independence in Panels

The most well-known test for cross section independence in econometrics has been the LM test by Breusch and Pagan (1980). However it is also known that it is only valid when the cross section dimension is much smaller than the time series dimension.

Pesaran (2004) proposes simple tests of error cross section dependence which are applicable to a variety of panel data models, including stationary and unit root dynamic heterogeneous panels with short T and large N. The proposed tests are based on average of pair-wise correlation coefficients of the OLS residuals from the individual regressions in the panel, and can be used to test for cross section dependence of any fixed order p, as well as the case where no *a priori* ordering of the cross section units is assumed, referred to as CD(p) and CD tests, respectively. The asymptotic distributions of these tests are derived and their power function analyzed under different alternatives. It is shown that these tests are correctly centred for fixed N and T, and are robust to single or multiple breaks in the slope coefficients and/or error variances. The small sample properties of the tests are investigated and compared to the Lagrange multiplier test of Breusch and Pagan using Monte Carlo experiments. It is shown that the tests have the correct size in very small samples and satisfactory power, and as predicted by the theory, quite robust to the presence of unit roots and structural breaks. The use of the CD test is illustrated by applying it to study the degree of dependence in per capita output innovations across countries within a given region and across countries in different regions. The results show significant evidence of cross dependence in output innovations across many countries and regions in the World.

Pesaran, Ullah and Yamagata (2006) propose a bias-adjusted normal approximation of the Lagrange multiplier (NLM) test of cross section independence (Breusch and Pagan, 1980) in the case of panel models with strictly exogenous regressors and normal errors. The exact mean and variance of the Lagrange multiplier (LM) test statistic are provided for the purpose of the bias-adjustments, and it is shown that the proposed tests have a standard normal distribution for fixed T as N tends to infinity. Importantly, the proposed bias-adjusted NLM tests are consistent even when Pesaran's (2004) CD test is inconsistent. Also alternative bias-adjusted NLM tests, which are consistent under local error cross section independence of any fixed order p, are proposed. The finite sample behavior of the proposed tests are investigated and compared to the LM, NLM, and CD tests. It is shown that the bias-adjusted NLM tests successfully control the size, maintaining satisfactory power in panels with exogenous regressors and normal errors, even when the cross section mean of the factor loadings is close to zero, where the CD test has little power. However, it is also shown that the bias-adjusted NLM tests are not as robust as the CD test to non-normal errors and/or in the presence of weakly exogenous regressors.

Sarafidis, Yamagata and Robertson (2006) propose a new testing procedure for error cross section dependence after estimating a linear dynamic panel data model with regressors by the generalised method of moments (GMM), which is valid with small T and large N. Importantly the approach examines whether error cross section dependence is left after including time dummies. The finite sample evidence suggests that the tests perform well, particularly the version based on the Blundell and Bond (1988) system GMM estimator. Also it is shown that the system GMM estimator, based only on partial instruments consisting of exogenous regressors, can be a reliable alternative to the standard GMM estimators under heterogeneous error cross section dependence. The proposed tests are applied to employment equations using UK firm data, and the results show little evidence of heterogeneous error cross section dependence.

4.5 Modelling House Prices

Holly, Pesaran and Yamagata (2006) provide an extensive application of the econometric methodology advanced under the project. This paper models the dynamic adjustment of real house prices across the States in the US, and examines the extent to which real house prices at the State level are driven by fundamentals such as real income, as well as by common unobserved shocks, and determines the speed of adjustment of house prices to macroeconomic and local disturbances. The paper takes explicit account of both cross sectional dependence and heterogeneity. This allows us to find a cointegrating relationship between real house prices and real per capita incomes. We are also able to identify a significant effect of State level population growth on changes in real house prices, but could only detect a small insignificant role for real interest rates on house prices. Using this model we then examine the role of spatial factors, in particular the effect of contiguous states by use of a weighting matrix. We are able to identify a significant spatial effect, even after controlling for State specific real incomes, and allowing for a number of unobserved common factors.

4.6 Global VAR Macroeconomic Modelling

International business cycle linkages among major economies and regions have attracted considerable attention. Pesaran, Schuermann and Weiner (2004) provide a compact global model called Global VAR (GVAR) model, which accounts for economic interlinkages across countries. Dees, Di Mauro, Pesaran and Smith (2007) extend this work in number of directions, and account for various transmission channels, including trade relationship and also financial linkages. Dees, Holly, Pesaran and Smith (2007) focus on testing long run macroeconomic relations for interest rates, equity, prices and exchange rates within a model of the global economy.

Financial institutions are ultimately exposed to macroeconomic fluctuations in the global economy. Pesaran, Schuermann and Weiner (2004) propose and build a compact global model

capable of generating forecasts for a core set of macroeconomic factors (or variables) across a number of countries. The model explicitly allows for the interdependencies that exist between national and international factors. Individual region-specific vector error-correcting models are estimated, where the domestic variables are related to corresponding foreign variables constructed exclusively to match the international trade pattern of the country under consideration. The individual country models are then linked in a consistent and cohesive manner to generate forecasts for all the variables in the world economy simultaneously. The global model is estimated for 25 countries grouped into 11 regions using quarterly data over 1979Q1-99Q1. The degree of regional interdependencies is investigated via generalized impulse responses where the effects of shocks to a given variable in a given country on the rest of the world are provided. The model is then used to investigate the effects of various global risk scenarios on a bank's loan portfolio.

Based on the econometric framework developed in Pesaran, Schuermann and Weiner (2004), Dees, Di Mauro, Pesaran and Smith (2007) present a quarterly global model combining individual country vector error-correcting models in which the domestic variables are related to the country-specific foreign variables. The global VAR (GVAR) model is estimated for 26 countries, the euro area being treated as a single economy, over the period 1979-2003. It advances research in this area in a number of directions. In particular, it provides a theoretical framework where the GVAR is derived as an approximation to a global unobserved common factor model. Using average pair-wise cross-section error correlations, the GVAR approach is shown to be quite effective in dealing with the common factor interdependencies and international comovements of business cycles. It develops a sieve bootstrap procedure for simulation of the GVAR as a whole, which is then used in testing the structural stability of the parameters, and for establishing bootstrap confidence bounds for the impulse responses. Finally, in addition to generalized impulse responses, the current paper considers the use of the GVAR for 'structural' impulse response analysis. Although, the GVAR model can be used for many different purposes, this paper focusses on the short term and long term implications of external shocks for the euro area economy, particularly in response to shocks to the U.S.. The results show that financial shocks are transmitted rapidly, and often get amplified as they travel from the U.S. to the euro area. Equity and bond markets seem to be far more synchronous as compared to real output and inflation. While the impact of an oil price shock on inflation is statistically significant, its impact on output remains limited. In contrast, the effects of a shock to the U.S. monetary policy for the euro area output and inflation are limited and not highly significant.

Dees, Holly, Pesaran and Smith (2007) focus on testing long run macroeconomic relations for interest rates, equity, prices and exchange rates within a GVAR model. It considers a number of plausible long run relationships suggested by arbitrage in financial and goods markets, and uses the global vector autoregressive (GVAR) model developed in Dees, Di Mauro, Pesaran and Smith (2007) to test for long run restrictions in each country/region conditioning on the rest of the world. Bootstrapping is used to compute both the empirical distribution of the impulse responses and the log-likelihood ratio statistic for over-identifying restrictions. The paper also examines the speed with which adjustments to the long run relations take place via the persistence profiles. Strong evidence is found in favour of the uncovered interest parity, and to a lesser extent for the Fisher equation across a number of countries. But the test results for the PPP are much weaker and far less conclusive. Also as to be expected, the transmission of shocks and subsequent adjustments in financial markets are much faster than those in goods markets.

5 Activities

5.1 Conferences, Seminars and Invited Lectures

M. Hashem Pesaran

Invited Lectures

Eleventh International Conference on Panel Data, Texas, June 2004

Keynote Speaker at MMF (Money Macro and Finance Research Group) 37th Annual Conference, Greece, September 'National and Global Macroeconometric Modelling, 2005.

Seminars

London Business School, UK, January 2004.
Nuffield College, Oxford, UK, January 2004.
London School of Economics, London, UK, February 2004.
Cass Business School, London, UK, March 2004.
IGIER, Università Bocconi, Milan, April 2004.
University of St Andrews, Scotland, April 2004.
Edinburgh University, Scotland, April 2004.
Warwick University, UK, May 2004.
Indiana University, Indianapolis, USA, November 2004.
Joint workshop of the ECB and the IMF on 'Global financial integration, stability and business cycles: exploring the links', November 2004.
EABCN Workshop, Brussels, November 2004.
Imperial College, London, UK, January 2005.
Bilkent University, Ankara, Turkey, April 2005.
Istanbul Bilgi Istanbul, Turkey, May 2005.
CASS Business School, London, UK, June 2005.
Princeton-Cambridge Conference, Princeton USA, September 2005.
Chinese Academy of Social Sciences (CASS), Beijing, September 2005.
Shanghai University of Finance & Economics, (SUFE), September 2005.
UCM Madrid, Spain, May 2006.
Swiss National Bank, Zurich, Switzerland, May 2006.
50 Years of Econometrics Conference, Rotterdam University, June 2006.
University of Amsterdam, Holland, June 2006.
The New School, New York , USA, October 2006.
New York University, USA, October 2006.
CASS Business School, London, October 2006.

Sean Holly

Conferences

International Conference on Panel Data, Cambridge, July 2006.

Seminars

European Central Bank, May 2005.
Bundesbank, September 2005.
European University Institute, Florence, November 2005.
Koc University, Istambul, December 2005.
University of Loughborough, December 2005.

Takashi Yamagata

Conferences

International Conference on Panel Data, Copenhagen, June 2005.
Econometric Society World Congress, London, August 2005.
International Conference on Panel Data, Cambridge, July 2006.

Econometric Society European Meeting, Vienna, August 2006.

Seminars

University of Manchester, April 2005.

5.2 Project Visitors

Professor C. Granger (University of California, San Diego), 20 - 23 April 2004.
Professor A. Ullah (University of California, Riverside), 21 June - 3 July 2004.
Professor C. Hsiao (University of Southern California), 4 -18 May 2006.
Professor J. Bai (New York University), 6 - 22 June 2006.

6 Outputs

Dees, S., F. Di Mauro, M.H. Pesaran and L.V. Smith (2007), "Exploring the International Linkages of the Euro Area: A Global VAR Analysis," *Journal of Applied Econometrics*, 22, 1-38.

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Holly, S., M.H. Pesaran and T. Yamagata (2006), "A Spatio-Temporal Model of House Prices in the US," Cambridge Working Papers in Economics (0654), revised March 2007.

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Kapetanios, G., M.H. Pesaran and T. Yamagata (2006), "Panels with Nonstationary Multifactor Error Structures," Cambridge Working Papers in Economics (0651).

Pesaran, M.H. (2004), "General Diagnostic Tests for Cross Section Dependence in Panels," Cambridge Working Papers in Economics (0435).

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Pesaran, M.H. (2007a), "A Pair-Wise Approach to Testing for Output and Growth Convergence," *Journal of Econometrics*, forthcoming.

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Pesaran, M. H. , Til Schuermann and Scott Weiner (2004), "Modelling Regional Interdependencies using a Global Error-Correcting Macroeconometric Model," *Journal of Business and Economics Statistics*, 22, 129-162.

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Pesaran, M.H., A. Ullah and T. Yamagata (2006), "A Bias-Adjusted LM Test of Error Cross Section Independence," Cambridge Working Papers in Economics (0641).

Pesaran, M. H. and T. Yamagata (2007), "Testing Slope Homogeneity in Large Panels," *Journal of Econometrics*, forthcoming.

Sarafidis, V., T. Yamagata and D. Robertson (2006), "A Test of Cross Section Dependence for a Linear Dynamic Panel Model with Regressors," mimeo, University of Cambridge.

6.1 Software

The software to compute the CCE estimators, panel unit root test statistics, cross section dependence tests are available upon request from us, and have been requested from many research communities all over the world.

7 Impacts

Our papers have been widely cited. For example, among others:

Barker, T. and De-Ramon, S.A. (2006), "Testing the Representative Agent Assumption: the Distribution of Parameters in a Large-Scale Model of the EU 1972–1998," *Applied Economics Letters*, 13, 395-398.

Byrne J.P. and M. Vecchi (2005), "Does Labour Productivity Flow Across Industries?: Estimation Robust to Panel Heterogeneity and Cross Sectional Correlation," National Institute of Economic and Social Research Discussion Paper (256).

Chan, F., T. Mancini-Griffoli and L.L. Pauwels (2006), "Stability Tests for Heterogeneous Panel Data," HEI Working Paper No: 24/2006.

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8 Future Research Priorities

The wide ranging research that this ESRC project has stimulated is likely to create further developments in spatial econometrics as the importance of properly accounting for cross sectional dependence becomes clear. Moreover, the nature of weak and strong forms of dependence, both spatially and economically is becoming an important area for further research.

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Kiefer, N.M. (1980), "A Time Series-Cross Section Model with Fixed Effects with an Intertemporal Factor Structure," Unpublished Manuscript, Department of Economics, Cornell University.

Lee, K.C. and M.H. Pesaran (1993), "The Role of Sectoral Interactions in Wage Determination in the UK Economy," *Economic Journal*, 103, 21–55.

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