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Non-Linear Perspectives for Population and Output Dynamics: New Evidence for Cliometrics

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New Evidence for Cliometrics

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1. Introduction

The mystery of economic growth has not been cracked in economics. The movement of the production potential of the industrialised nations over long periods of time is still in the centre of the very latest economic (Aghion and Howitt, 1998; Temple, 1999) and cliometric (Abramovitz, 1986; Crafts, 1987; Darné and Diebolt, 2004; Goldin, 1995; McCloskey, 1987; North, 1994; Wright, 1971) debates. This preoccupation is far from new. The classical economists were already concerned about how to increase welfare by increasing growth (Smith, 1776). The subject remained controversial after World War II, with the theoretical debate on the long-term stability of market economies. However, through Solow’s (1956) economic growth model neo-classical thinking gradually exerted its power. Its reasoning is clear and it also explains numerous aspects related to economic growth which are summarised perfectly in Kaldor’s (1963) six ‘stylised facts’. At the same time—perhaps paradoxically—scientific interest in work on growth and economic cycles disappeared. There were two main reasons for this. Firstly, the short-sightedness of economists whose attention was centred almost exclusively on the study of short movements and secondly, the comparative weakness of theoretical models incapable of solving the aspects that remain unexplained by the different theories of growth. This partially explains why the post-war neo-classical models are unsatisfactory. Indeed, in the long run, they only account for economic growth by involving exogenous factors (except for Ramsey’s (1928) model that was rediscovered very recently) and in this case the technical progress achieved without cost outside the economic system. In addition, Solow’s reference model does not provide any way of explaining the divergence in growth rates at the international level, as with the idea of long-run equilibrium, all countries should progress at identical, exogenous rates of technical progress. Similarly, it should be noted that the hypothesis of the systematic existence of a negative correlation between income level and economic growth rate is not based on any satisfactory empirical verification. Finally, nothing really corroborates the convergence hypothesis, that is to say the transfer of capital from the richest to the poorest countries (Bara and Sala-I-Martin, 1992, 1995). However, the work of Lucas (1988) and Romer (1986, 1990) attracted attention, and the 1980s marked a renaissance of the neo-classical theory of growth. The prime objective was to go beyond the weakness
of the old theoretical models. The aim was also to answer new questions: what are the determinants of sustainable economic growth? Can technical progress alone increase social welfare or can capital accumulation also lead to a permanent increase in per capita income? What are the factors of production that engender sustainable economic growth: physical capital, environmental capital, human capital, social capital or technological knowledge? What are the mechanisms that guarantee growth over a long period for a market economy? Finally, what is/are the market structure/s within which economic growth can be achieved? Strengthened through these questions, the debate on the determinants of the economic growth process has attracted considerable attention, both in the importance of its implications in terms of economic policy and in the number of theoretical and empirical analyses that it engendered. Curiously, population dynamics is often absent from the theoretical developments and empirical verifications (Fogel, 1994; Jones, 1998) or appears implicitly under the heading ‘human capital’. As a possible response to this, our focus in this paper is to identify, in econometric history terms, both the short and long run nature of any causal movement between population and output dynamics, here in the case of France by using recent methods for linear cointegration and non-linear Granger causality. The main contribution is the use of a new technique, the Multivariate Surrogate Data, to validate empirical findings in favour of non-linear linkages between economic series.

The importance of using non-linear methods in order to explore complex structures and relationships between macroeconomic variables has been underlined in a special issue totally consecrated to Non-linear Macroeconomic Dynamics, edited by Kyrtsou and Palivos (2006). From a mathematical point of view a non-linear feedback reflects a bi-directional causal behaviour. Catching non-linear feedbacks among macroeconomic series can have very interesting economic implications since we can obtain information about the intensity and the nature of inter-dependences. As Kyrtsou (2005b) reports, the fact that in non-linear systems the effect is not proportional to its cause makes so attractive the discovery of non-linear dynamics between economic series. Thus quantifying on the one hand and qualifying on the other hand observed phenomena could lead to a better understanding of the economic reality.
The outline of the paper is as follows. In Section 2, methodological issues are discussed. We apply the empirical procedure to the annual historical gross domestic product (GDP) and population series of France. Section 3 presents implications of empirical findings and suggestions for further extensions.

2. Methodology

The output data used here refer to GDP. This broad aggregate covers the output of the whole French economy, and excludes income received from or paid for foreign investment. For 1950 onwards, the data are derived from currently collected official estimates based on almost identical concepts, as published by OECD. For the years before 1950, most of the historical estimates are based on substantial statistical research by distinguished scholars (Toutain, 1997 especially), and emanate from the governmental statistical service responsible for making the more recent official estimates. In order to compare levels of output, it is useful to have a unit which expresses to comparative value of their currencies better than exchange rates.

The Maddison series (1995, 2001, 2003 and [http://www.ggdc.net/index.html](http://www.ggdc.net/index.html)) give the level of output in 1990 US Dollars for selected years, corrected to offset the impact of boundary changes. The population series are adjusted to refer to mid-year. The series include all nationals present in the country, armed forces stationed abroad, and merchant seaman at sea. Aliens are included only if they are permanently settled. All data are annual and also not seasonally adjusted in order to avoid distortions in their inherent dynamics. They begin in 1820 and end in 2001 (182 observations).

All tests, except the Bierens’ test for linear cointegration, are applied to the growth rates (logarithmic differences) of the series. The methodological path can be schematized in an explicit manner in Figure 1. We begin with the Bierens Lambda-Min test for linear cointegration. This enables the performance of the non-linear Granger causality test at the next step. Figure 1 includes parts of the Kyriatsou and Labys (2006) procedure for testing dynamic non-linearity. The new of our presentation is that results are reinforced by a validation procedure based on the multivariate surrogate data technique.
Linear cointegration not found

Logarithm of prices

Tests for linear cointegration

Linear cointegration found

Test for non-linear Granger causality (GC)

Validation Procedure

on growth rates

on surrogate series

accept non-linear GC

reject non-linear GC

accept non-linear GC

reject non-linear GC

obtaining different conclusions

obtaining identical conclusions

Non-linear Granger causality found

Non-linear Granger causality not found

Evidence of dynamic non-linearity

No evidence of non-linearity

Bi-directional non-linear causality (Evidence for non-linear feedback)

Unidirectional non-linear causality (No evidence for non-linear feedback)

Figure 1: Procedure for identifying and validating non-linear feedback
2.1 Bierens (1997) Lambda-Min Test for Linear Cointegration

The lambda-min test has been developed by Bierens (1997). It is in the same spirit as Johansen’s lambda-max test. Johansen’s original approach is based on the following Error Correction Model of the q-variate unit root process \( x_t \), for \( t=0,1,2\ldots,n \):

\[
\Delta x_t = \sum_{j=1}^{p-1} \Pi_j \Delta x_{t-j} + \gamma \beta^T x_{t-p} + e_t
\]

where the \( \Pi_j, j>0 \), are \( q \times q \) and \( \beta \) and \( \gamma \) are \( q \times r \) parameter matrices with \( r \) the number of cointegrating vectors, and \( e_t \) are i.i.d. errors that follow \( N_q(0, \sigma) \). By stepwise elimination of all the parameter matrices in the likelihood function, except the matrix \( \beta \), Johansen shows that the ML estimator of \( \beta \) can be derived from the eigenvectors of the generalized eigenvalue problem \( \det(S_{oo}^{-1}S_{po}S_{op}^{-1}S_{pp})=0 \), where \( S_{ij}=(1/n) \sum_{t=1}^{n} R_{i,t}R_{j,t}^T \), \( i,j=0,p \), with \( R_{0,t} \) the residual vector of the regression of \( \Delta x_t \) on \( \Delta x_{t-1}, \ldots, \Delta x_{t-p+1} \), and \( R_{p,t} \) the residual vector of the regression of \( x_{t-p} \) on \( \Delta x_{t-1}, \ldots, \Delta x_{t-p+1} \). Moreover, the ordered eigenvalues \( \hat{\lambda}_1 \geq \ldots \geq \hat{\lambda}_q \) involved can be used for testing hypotheses about the number of cointegrating vectors. In particular, Johansen proposes two LR tests for the number of cointegrating vectors, the trace test and the lambda-max test. The trace test tests of \( H_q \) against \( H_{q-1} \) is \( n \hat{\lambda}_{r+1} \). Here Johansen proves that \( (\hat{\lambda}_1, \ldots, \hat{\lambda}_q) \) converges in distribution to \( (c_1, \ldots, c_q, \ldots, 0, \ldots, 0) \), where the \( c_j \)'s (\( j=1, \ldots, r \)) are positive constants and \( n(\hat{\lambda}_{r+1}, \ldots, \hat{\lambda}_q) \) converges in distribution to \( (\epsilon_1, \ldots, \epsilon_q) \), where the \( \epsilon_j \)'s are positive random variables. Bierens shows that his test can mimic Johansen’s tests with the simple transformation of the generalised eigenvalues \( \hat{\lambda}_{j,m} \) (\( m \geq q \) is a natural number) by \( \hat{\mu}_{j,m} = 1/(n \sqrt{\hat{\lambda}_{q+1-j,m}}) \) and the replacement of the Johansen’s eigenvalues in his lambda-max and trace tests by the \( \hat{\mu}_{j,m} \)'s. As one can see from Table 1, Bierens’ method indicates the existence of one cointegrating equation. This means that in the long run only a linear dependence
between GDP and population is found. According to the procedure in Figure 1, if linear dependence in
the long run exists, then we study the nature of dependence in the short run using the Hiemstra and
Jones (1994) test for non-linear Granger causality.

Table 1: Testing for linear cointegration using the Bierens’ method

<table>
<thead>
<tr>
<th>Hypotheses</th>
<th>5% critical region</th>
<th>Bierens’ $\lambda_{\text{min}}$ test statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_0$</td>
<td>$H_a$</td>
<td></td>
</tr>
<tr>
<td>$r = 0$</td>
<td>$r = 1$</td>
<td>$0.00000$</td>
</tr>
<tr>
<td>$r = 1$</td>
<td>$r = 2$</td>
<td>$1.11315$</td>
</tr>
</tbody>
</table>

*If the computed statistic is within the critical region then we reject the $H_0$. 

2.2 Test for Non-linear Granger Causality

The method for non-linear Granger causality used here is the modified version of the Baek and Brock (1992) test developed by Hiemstra and Jones (1994). The important addition of the modified test is that it relaxes Baek and Brock’s assumption that the time series to which the test is applied are mutually independent, individually independent and identically distributed. Instead, it is possible that each series presents short-term temporal dependence.

To define non-linear Granger causality, assume that there are two strictly stationary and weakly dependent time series $\{X_t\}$ and $\{Y_t\}$, $t=1,2,\ldots,T$. Denote the $m$-length lead vector of $X_t$ by $X_t^m$ and the $L_x$-length and $L_y$-length lag vectors of $X_t$ and $Y_t$, respectively. For given values of $m$, $L_x$, and $L_y \geq 1$ and for $e > 0$, $Y$ does not strictly Granger-cause $X$ if:

$$
\Pr\left(\|X_t^m - X_t^m\| < e \mid \|X_{t-L_x}^{L_x} - X_{t-L_x}^{L_x}\| < e, \|Y_{t-L_y}^{L_y} - Y_{t-L_y}^{L_y}\| < e\right) = 0
$$

where $\Pr(.)$ denotes probability and $\|\|$ denotes the maximum norm. The probability of the left side of equation (2) is the conditional probability that two arbitrary $m$-length lead vectors of $\{X_t\}$ are within a distance $e$ of each other, given that the corresponding $L_x$-length lag vectors of $\{X_t\}$ and $L_y$-length lag vectors of $\{Y_t\}$ are within $e$ of each other. A test based on equation (2) can be implemented by writing it in terms of the corresponding ratios of joint probabilities:
\[
\frac{C_1(m + L_x, L_y, e)}{C_2(L_x, L_y, e)} = \frac{C_3(m + L_x, e)}{C_4(L_x, e)}
\] (3)

where \(C_1, C_2, C_3,\) and \(C_4\) are the correlation-integral estimates of the joint probabilities. Hiemstra and Jones (1994) discuss how to derive the joint probabilities and their corresponding correlation-integral estimators. Assuming that \(\{X_t\}\) and \(\{Y_t\}\) are strictly stationary, weakly dependent, and satisfy the mixing conditions of Denker and Keller (1983), if \(\{Y_t\}\) does not strictly Granger-cause \(\{X_t\}\), then:

\[
\sqrt{n} \left[ \frac{C_1(m + L_x, L_y, e, n)}{C_2(L_x, L_y, e, n)} - \frac{C_3(m + L_x, e, n)}{C_4(L_x, e, n)} \right] \rightarrow N(0, \sigma^2(m, L_x, L_y, e))
\] (4)

where \(n = T + 1 - m - \max(L_x, L_y)\). The consistent estimator of the variance \(\sigma^2(m, L_x, L_y, e)\) is given in Hiemstra and Jones (1994).

All empirical works applying the modified test for non-linear Granger causality use the residual series from a VAR model and not the initial returns. In a series of papers (Kyrtsou (2005a, 2006), Kyrtsou and Terraza (2003), Kyrtsou et al. (2004), Kyrtsou and Malliaris (2005), Kyrtsou and Serletis (2006), Kyrtsou and Volrow (2005)) financial series have been found to be highly complex. As Kyrtsou (2005b) discusses, in presence of such dynamics, linear filtering of data before the application of the Hiemstra and Jones test can lead to serious distortions\(^1\). So, in this paper the test is applied directly to the original returns series. The results are given in Table 2.

\(^1\)Diks and Panchenko (2005) show that when data are generated by stochastic processes the Hiemstra and Jones (1994) test can fail to detect the correct causal relationship. In this paper, the application is based on the empirical findings in Kyrtsou (2005c). The joint use of the Hiemstra and Jones (1994) and Multivariate Surrogate data techniques ensure the efficient identification of causal relationships between noisy chaotic series.
As it can be seen the presence of non-linear feedback or bi-directional non-linear Granger causality is obvious. In other words, GDP and population are non-linearly dependent in the short run. In economic terms this type of feedback reveals the intensity of the influence of GDP into population and vice versa. The short-term character of this behaviour can be highly informative about the direct impact of the population variation on the French economic growth. Given the theoretical and empirical difficulties to identify the true causal relationships between real data in presence of ARCH effects, outliers, and complex dynamics, we considered that the empirical scheme followed by Kyrtsou and Labys (2006) for capturing non-linear feedbacks should be extended. In this aim the additional validation step of the multivariate surrogate data used in Kyrtsou (2005c) is incorporated in Figure 1.

2\text{Lx}=\text{Ly}$ denotes the number of lags on the returns series used in the test. CS and TVAL are the difference between the two conditional probabilities in equation (3) and the standardised test statistic in equation (4), respectively. A common scale parameter $\epsilon=1\sigma$ is used, where $\sigma$ is the standard deviation of the returns series.
2.3 Multivariate Surrogate Data Technique

In the present work, we are based on the method described by Schreiber and Schmitz (2000) to construct multivariate surrogate data for the growth rates of GPD (dlgdp) and population (dlpop). In this technique, linearly stochastic time series pairs sdlgdp-sdlpop are generated from the real time series pairs dlgdp-dlpop with the linear correlations within each component time series and the cross correlation between them preserved. Such surrogate data have no non-linear properties. Then, the non-linear Granger causality test is applied to the surrogate series. Following Figure 1, if the value of the statistic calculated on the original data set is different from the sets of values obtained on the surrogate data, we have a clear indication for the rejection of the null. In each calculation 20 surrogate series were computed. The hypotheses in the present context can be formulated as follows:

\[ H_0: \text{No evidence for non-linear Granger causality} \]

\[ H_\alpha: \text{Evidence for non-linear Granger causality} \]

The results from the application of the Hiemstra and Jones test to the surrogate series are reported in Table 3. The test statistics is significant only for Lx=Ly=1 and 2 at 5% and 10% respectively. This indicates a unidirectional non-linear causality. Nevertheless, if we want to compare Table 2 and 3 we have to keep the same level of statistical significance for both cases. Consequently, by taking as a base of comparison the critical value of 2.326 for 1% statistical significance from the first two delays in italics in Table 2, we can hence conclude that no evidence for non-linear causality is obtained on the surrogates. According to the graphical representation of our procedure in Figure 1, having different conclusions for original and surrogate data means clear presence of non-linear causality. In the present example a bi-directional non-linear causality is archived among output and population.
### Table 3: Non-linear Granger Causality Test

<table>
<thead>
<tr>
<th></th>
<th>sdlgd → sdlgdp</th>
<th></th>
<th>sdlgpop → sdlgd</th>
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<tr>
<td>Lx=Ly</td>
<td>CS</td>
<td>TVAL</td>
<td>Lx=Ly</td>
<td>CS</td>
</tr>
<tr>
<td>1</td>
<td>0.0247</td>
<td>1.7423*</td>
<td>1.0046</td>
<td>0.3543</td>
</tr>
<tr>
<td>2</td>
<td>0.0263</td>
<td>1.4913*</td>
<td>0.0086</td>
<td>0.3556</td>
</tr>
<tr>
<td>3</td>
<td>0.0199</td>
<td>0.846</td>
<td>0.0101</td>
<td>0.4232</td>
</tr>
<tr>
<td>4</td>
<td>0.028</td>
<td>0.9435</td>
<td>0.0131</td>
<td>0.376</td>
</tr>
<tr>
<td>5</td>
<td>0.036</td>
<td>0.9411</td>
<td>0.007</td>
<td>0.2139</td>
</tr>
<tr>
<td>6</td>
<td>0.0127</td>
<td>0.3015</td>
<td>0.0213</td>
<td>0.4455</td>
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<tr>
<td>7</td>
<td>0.0054</td>
<td>0.0086</td>
<td>0.0062</td>
<td>0.1859</td>
</tr>
<tr>
<td>8</td>
<td>-0.0095</td>
<td>-0.108</td>
<td>0.04</td>
<td>0.7624</td>
</tr>
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</table>

*: An asterisk indicates significance. The critical value at 1% for an one-sided test is 2.326; for 5% is 1.645; for 10% is 1.280.

### 3. Implications

The literature on long-run economic growth and especially on new growth theories is diverse in nature. However, the structure of the models is identical, with endogenous growth becoming possible after the introduction of a new accumulation factor whose results are at least constant. This factor makes it possible to compensate the decreasing returns of capital accumulation. Growth factors other than the traditional factors of capital and labour are modelled for the first time. However, it would seem that the results of the models depend very strongly on research hypotheses that have not yet been verified. According to the thinking of Lucas, in particular, the source of economic growth lies in the unlimited accumulation of human capital. This boundless increase in human capital is based on major hypotheses of non-decreasing returns of technology and training and on the existence of externalities. In fact, in the long run and as in Uzawa’s model (1965), economic growth might just as easily be nil. In the model category inspired by the work of Romer, economic growth is a function of research and development, the latter depending on the share of human capital allocated to the research sector. Accumulation of knowledge (innovations) forms the engine of growth and this accumulation can be
unlimited because of the very nature of knowledge, which is a non-rival good with partially exclusive use. The other models achieve self-maintained growth in an identical way by means of hypotheses concerning the non-decreasing returns of the new factors of accumulation. This fundamental criticism opens up considerable research prospects, in particular with regard to empirical verifications. The latter may either confirm the endogenous growth hypotheses or, more simply, encourage a return to the Solowian tradition, since, *a priori*, there is nothing to prevent the inclusion of education, research and development, public expenditure, and population growth etc. in the model defined by Solow in 1956.

In this paper, in order to explain the causal relation between population and output, we consider population as an investment. However, the allocation of resources to population growth as an investment raises the major problem of knowing the nature of this investment. Indeed, population can be considered either as a directly productive investment or as an investment in infrastructure.

In the first case, population growth incorporates in a society a kind of capital that increases the effectiveness of the economy. Nevertheless, the possibility of investment induced by such an investment remains conditional. Indeed, we should not forget that material investment is considered as a driving force behind economic growth because it is performed with a view to production that should find outlets. In other words, production means are created with a reasonable prospect of their being used. As a result, it is not certain that an analogous forecasting calculation is performed for population accumulation. Indeed, is there a requirement for the economic use of the *products* of the population growth, that is to say the adaptation of population and fertility rates to the absorption capacity of the economy?

In the second case, population is considered as an investment in infrastructure. This changes the perspective elaborated in the first case. Population appears more as a condition for development and no longer a driving force behind growth. Here we stress the complementary nature of population in relation to the labour factor, which is in turn complementary with regard to capital. Population then becomes a condition for the effectiveness of material means.

The problem of the economy’s capacity to absorb the products of a growing population can now be approached using two notions.
The first notion sees the investment in infrastructure as a driving force behind investment. With regard to material investments, it leads to seeking a logical definition of the infrastructure corresponding to a given growth level (desired and attainable). We consider that this infrastructure encourages the adoption of a policy of technical operations that gives rise to new production activities and has a stimulating effect. Transposed to population, this analysis leads to recommending a certain population structure corresponding to a certain professional structure suited to the level of economic growth desired. In these terms, the supply of population may have a stimulating effect insofar as the availability of more persons can encourage certain activities and form an incitement to use certain techniques. Nevertheless, such a stimulating effect is by definition delayed, random and partial. It includes the risk of not using qualified persons or using them badly. The investment in infrastructure thus becomes an investment not followed by production, that is to say economic waste.

The second notion considers investment in infrastructure as a simple accompanying investment. With regard to material investments, it leads to defining the infrastructure required by the prospects of economic growth related to directly productive investments. Unless there are differences in time lags inherent to the various investment operations, we can say that investment in infrastructure follows investment in production instead of preceding it. In other words, the former is modulated by the latter. Application of this reasoning to population means that the flow of the population is adapted to forecastable future demand for labour with various levels and types of qualifications.

Finally, there must be economic use of the *products* of the demographic system whether population is considered as a productive investment or as an investment in infrastructure. In the latter case, the results of our analysis —the bi-directional non-linear causality— lead us to considering that, for the historical case of France, the investment in population is more in the accompanying category as a ‘driving force’ investment for growth. The more interesting of the bi-directional relationship between French output and population series is its non-linear nature. The non-proportional character of non-linearity sheds lights on the specific dynamics between those variables, since an increase in population can lead via the feedback effect to unexpected variations in output.
References


<table>
<thead>
<tr>
<th>Working Paper</th>
<th>Authors</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>WP2006-1</td>
<td>Olivier DARNÉ, Claude DIEBOLT</td>
<td>&quot;Claometrics of Academic Careers and the Impact of Infrequent Large Shocks in Germany before 1945&quot;</td>
</tr>
<tr>
<td>WP2006-2</td>
<td>Claude DIEBOLT, Catherine KYRTSOU</td>
<td>&quot;Non-Linear Perspectives for Population and Output Dynamics: New Evidence for Cliometrics&quot;</td>
</tr>
<tr>
<td>WP2006-3</td>
<td>Claude DIEBOLT, Karine PELLIER</td>
<td>&quot;L'intérêt des systèmes de gestion de bases de données relationnels en cliométrie&quot;</td>
</tr>
<tr>
<td>WP2006-4</td>
<td>Claude DIEBOLT, Jean-Pascal GUIRONNET</td>
<td>&quot;The Dynamics of Education Returns&quot;</td>
</tr>
<tr>
<td>WP2006-5</td>
<td>Claude DIEBOLT, Jean-Pascal GUIRONNET</td>
<td>&quot;Vers une théorie économique de la suréducation ?&quot;</td>
</tr>
<tr>
<td>WP2006-6</td>
<td>Claude DIEBOLT, Mishra TAPAS</td>
<td>&quot;Cliometrics of the Abiding Nexus between Demographic Components and Economic Development&quot;</td>
</tr>
<tr>
<td>WP2006-7</td>
<td>Magali JAOUL</td>
<td>&quot;Climétrie de l'engorgement en France. Evaluation théorique et empirique&quot;</td>
</tr>
<tr>
<td>WP2006-8</td>
<td>Claude DIEBOLT, Antoine PARENT</td>
<td>&quot;Were the Anomalies in the Sterling-Franc Exchange Rate Regulation during the Mid-19th Century?&quot;</td>
</tr>
<tr>
<td>WP2006-9</td>
<td>Claude DIEBOLT</td>
<td>&quot;Progrès technique et cycles économiques dans la pensée allemande de l’entre-deux-guerres : l’apport d’Emil Lederer&quot;</td>
</tr>
<tr>
<td>WP2006-10</td>
<td>Claude DIEBOLT</td>
<td>&quot;Croissance et éducation&quot;</td>
</tr>
<tr>
<td>WP2006-11</td>
<td>Mohamed CHIKHI, Claude DIEBOLT</td>
<td>&quot;Nonparametric Analysis of Financial Time Series by the Kernel Methodology&quot;</td>
</tr>
<tr>
<td>WP2006-12</td>
<td>Claude DIEBOLT, Antoine PARENT</td>
<td>&quot;A Note on Juglar, Bonnet and the Intuition of the Interest Parity Relation&quot;</td>
</tr>
</tbody>
</table>