BANCA D'ITALIA
EUROSISTEMA

Temi di Discussione

(Working Papers)

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Number 881

September 2012

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Number 881 - September 2012

ISSN 1594-7939 (print)

ISSN 2281-3950 (online)

Printed by the Printing and Publishing Division of the Bank of Italy

ON DETECTING END-OF-SAMPLE INSTABILITIES

by Fabio Busetti*

Abstract

Tests of parameter instabilities are likely to have low power when change-points occur towards the end of the sample. This paper considers various modifications of existing tests and introduces new statistics designed to have high power in such circumstances. The properties of both Wald-type tests of a one-time shift in the parameters and locally most powerful (LMP) tests against the hypothesis of random walk coefficients are examined. It is proposed to take functionals of the Wald and LMP statistics such that either the set of possible change-points is restricted to the last part of the sample or the occurrence of change-points is given increasing weight throughout the sample. For the case of an unknown end-of-sample change-point, the LMP-type tests appear to have, in general, better properties than Wald-type tests, even against the hypothesis of a one-time shift in the parameters. Empirical illustrations describe the use of the tests for detecting structural changes at the time of the 'Great Recession'.

JEL Classification: C12, C22.
Keywords: structural breaks, time-varying parameters.

Contents

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1 Introduction

The detection of changepoints and parameter instabilities has attracted considerable attention in the statistics and econometrics literature. If the location of a potential changepoint is known in advance, the Wald test of Chow (1960) has optimal properties against the hypothesis of a one-time shift in the parameters in a standard regression framework. If no prior information is available on the location, the solution proposed by Quandt (1960) is to take the maximum of the Wald statistics computed over the set of possible changepoints. The asymptotic representation and the critical values of this 'Sup test' have been derived by Andrews (1993). Andrews and Ploberger (1994) have shown that better properties can be obtained by taking some averages of the Wald statistics instead of the maximum. Similar, and asymptotically equivalent, tests can be obtained using the LM and LR statistics.

A different class of parameter instabilities tests has been derived against the alternative hypothesis of random walk coefficients. In a linear model with potentially time-varying parameters, locally most powerful (LMP) tests have been proposed by Nyblom and Makelainen (1983), King and Hillier (1985) and Nyblom (1989); the latter paper is in fact concerned with a more general hypothesis of martingale time-variation in the parameter which nests the cases of random walk coefficients and 'discrete' parameter shifts randomly occuring in the sample. Elliott and Muller (2006) follow a similar approach, but they focus on tests that maximize the power against a chosen, fixed alternative hypothesis, not necessarily close to the null as for the LMP statistics. Their paper provides a generalization of previous results of Franzini and Harvey (1983) and Shively (1988).

A further alternative way to detect parameter instabilities is to examine the sequence of regression coefficients estimated with an increasingly large data set, as in the 'fluctuation tests' of Ploberger et al. (1989). Similarly, the CUSUM tests of Brown et al. (1975) look at the behaviour of the partial sum process of (squared) recursive OLS residuals; more generally, partial sums of Kalman filter residuals were considered in Harvey (1989, p. 256-258) for unobserved components models. Unlike the Wald and LMP statistics, these tests have been proposed without reference to any specific alternative hypothesis.[1] A detailed survey of the testing methods described above is given in Stock (1994).[2]

[1] In discussing the article by Brown et al. (1975), Harvey notes that the power of these tests may however be low '...in the presence of many types of structural change likely to occur in practice' (p. 180).

[2] The related issue of estimating the time of changepoints is considered in Bai (1997) and Bai and Perron (1998) in a linear regression set up. A further strand of the

The ability of the tests to reject the null hypothesis of stability clearly depends on the number of 'post-changepoint' observations relative to the sample size. The tests are then likely to display low power when a changepoint occurs in the late part of the sample. Failing to detect end-of-sample parameter changes has particularly pernicious implications if the models are used for making predictions, since these instabilities will largely affect the model's forecasts.

This paper therefore considers various modifications of existing tests and introduces new statistics designed to have high power in such circumstances. The properties of both Wald-type tests of a one-time shift in the parameters and locally most powerful (LMP) tests against the hypothesis of random walk coefficients are examined. It is proposed to take functionals of the Wald and LMP statistics such that either the set of possible changepoints is restricted to the last part of the sample or the occurrence of changepoints is given increasing weight throughout the sample. Asymptotic critical values of the tests are provided and their properties are evaluated in finite samples.

The Wald-type tests examined here extend the range of applications of the results of Andrews and Ploberger (1994). The LMP-type tests are derived against the alternative hypothesis of a switch from stable to random walk coefficients at some point in the sample, thus generalizing Nyblom (1989), who considered time varying coefficients throughout the whole sample. A similar hypothesis was considered by Busetti and Taylor (2004) in a time series framework and by Andrews and Kim (2006) for the residuals of a cointegrating regression.

Our results show that, for the case of an unknown end-of-sample changepoint, the LMP-type tests appear to have, in general, better properties than the Wald-type tests, even against the hypothesis of a one-time shift in the parameters. However, for dynamic models, the Wald-type tests turn out to be more (less) powerful in the case of a decrease (increase) in the degree of persistence of the data. When the end-of-sample changepoint is known, the subsampling tests *à la* Andrews (2003) have the best properties, as expected, but they display low power if the instability is not correctly located.

In summary, the paper proceeds as follows. Section 2 describes the testing framework and provides the new and modified test statistics aimed at detecting end-of-sample instabilities with the associated critical values. The size and properties of the tests are evaluated by means of Monte Carlo simulations in Section 3. Section 4 contains two empirical

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literature has instead been concerned with testing stability of the whole distribution of a time series; see, *inter alia,* Picard (1985), Inoue (2001), Lee and Nah (2005), Busetti and Harvey (2010, 2011).

illustrations on the use of the tests. Section 5 concludes.

2 End-of-sample instability tests in a linear regression model: statistics, distributions and critical values

We consider a linear regression model with $K = k_1 + k_2$ regressors $x_t = (x'_{1t}, x'_{2t})'$ and $T = n + m$ observations, where a breakpoint can occur in the second subsample of size m,

$$y_t = \begin{cases} x'_{1t}\beta_1 + x_{2t}'\beta_2 + u_t & \text{for } t = 1, ..., n \\ x'_{1t}(\beta_1 + \delta_t) + x'_{2t}\beta_2 + u_t & \text{for } t = n+1, ..., n+m \end{cases} \tag{1}$$

with u_t being an i.i.d. disturbance such that $E(u_t|x_t) = 0$ and $E(u_t^2|x_t) = \sigma^2$; the regressors x_t satisfy standard assumptions of stationarity with $p\lim T^{-1}\sum_{t=1}^{T} x_t x_t'$ being a positive definite matrix. The null hypothesis of parameter stability is $H_0 : \delta_t = 0$ for all $t = n+1, ..., n+m$. Under the alternative hypothesis $\delta_t \neq 0$ for some t. The model allows parameter instability to occur only for a subset of the regressors; the term $x'_{2t}\beta_2$ disappears if the presence of instabilities is investigated for all the coefficients.

2.1 Wald-type tests

A standard F-test has optimal properties against the hypothesis of a one-time structural change in the coefficients that occurs at a known fraction $\pi = 1 - \frac{m}{T} \in (0,1)$ of the sample size. Let $x_t(\pi) = (x'_{1t},\ x'_{2t},\ x'_{1t}1(t \geq [\pi T]))'$, where the notation $[z]$ indicates the nearest integer to z. Denote by Q and $Q(\pi)$ the sum of squared OLS residuals from regressing y_t on x_t and y_t on $x_t(\pi)$, respectively. The F-statistic is

$$F(\pi) = \frac{(Q - Q(\pi))/k_1}{Q(\pi)/(T - 2k_1 - k_2)}, \tag{2}$$

that compares the statistical fit of the restricted and unrestricted models, the latter allowing a structural change in the coefficients of x_{1t}. This is a standard Wald test; the null limiting distribution of $k_1 F(\pi)$ is a χ^2 with k_1 degrees of freedom.

If the location of the parameter change is not known a priori, Quandt (1960) proposes to take the maximum of the F-statistics over the set of possible breakpoints,

$$\text{Sup-F} = \underset{\pi \in \Pi}{Sup}\ F(\pi) \tag{3}$$

where Π is a closed subset of $(0,1)$. Andrews and Ploberger (1994) show that taking averages of the F-statistics yields better properties than those of the Sup-F test. Here we consider their so-called Exp-F test statistic, defined as

$$\text{Exp-F} = \log \int_{\pi\in\Pi} \exp\left(\frac{k_1}{2} F(\pi)\right) dJ(\pi), \tag{4}$$

where $J(\pi)$ is a chosen weight function (i.e. probability measure) on the values of $\pi \in \Pi$.

Andrews (1993) shows that, under the null hypothesis of no structural change, for each $\pi \in \Pi$ the limit distribution of $F(\pi)$ can be represented as a quadratic form of a Brownian Bridge process,

$$F(\pi) \xrightarrow{d} F_\infty(\pi) \equiv k_1^{-1} \frac{B_{k_1}(\pi)' B_{k_1}(\pi)}{\pi(1-\pi)},$$

where $B_{k_1}(\pi) = W_{k_1}(\pi) - \pi W_{k_1}(\pi)$ and $W_{k_1}(\pi)$ is a k_1-dimensional Brownian motion. Thus, by an application of the Continuous Mapping Theorem, the limiting distributions of the statistics (3)-(4) are obtained by replacing $F(\pi)$ with $F_\infty(\pi)$ in their definitions.

The asymptotic critical values for k_1Sup-F are given in Andrews (1993, p.840) for different Π's; note that the critical values provided by Andrews need to be divided by k_1 to be used with our statistic (3) that is defined in terms of F-statistics instead of the equivalent Wald statistics considered in those papers.

As noted by Andrews and Ploberger (1994), in order to get higher power against end-of-sample instability, the Sup-F and Exp-F tests can be computed restricting Π to the latest part of the sample; here we consider the latest 25% and 10% of the sample.

The asymptotic critical values for Exp-F provided by Andrews and Ploberger (1994) pertain to the case of equal weights for all possible breakpoints (i.e. a uniform measure on Π).[3] A simple modification of the Exp-F test aimed at achieving higher power against end-of-sample instabilities is to abandon the case of uniform weights in favour of giving higher weights against changepoints occuring later in the sample. Here we propose a weighting scheme that increases linearly throughout the sample, i.e. define the modified statistic

$$\text{Exp-F}_{LIN} = \log \int_{\pi\in\Pi} \exp\left(\frac{k_1}{2} F(\pi)\right) \pi d\pi.$$

The critical values of Exp-F$_{LIN}$ are provided in Table 1 for $\Pi = [.01, .99]$ and for a number of potentially changing parameters k_1 between

[3]In practice, for a uniform measure on $\Pi = [\pi_0, \pi_1]$, the test statistic is computed as Exp-F$= \log \sum_{t=[\pi_0 T]}^{[\pi_1 T]} \exp\left(\frac{k_1}{2} F(\pi_t)\right) / T^*$, where $\pi_t = t/T$ and $T^* = [\pi_1 T] - [\pi_0 T] - 1$.

1 and 5. The table also provides the critical values for the Sup-F and Exp-F where $\Pi = [.05, 95]$, $[.01, .99]$, $[.75, 99]$ and $[.90, .99]$.

2.2 LMP-type tests

Under Gaussianity, a locally most powerful test of the null hypothesis of parameter stability against the alternative of random walk coefficients has been derived by Nyblom and Makelainen (1983) for a level plus noise model and then adapted to a regression framework by King and Hillier (1985) and Nyblom (1989); an extension to multivariate time series model is considered in Nyblom and Harvey (2000). The LMP test statistic is given by

$$L = \widehat{\sigma}^{-2} T^{-2} \sum_{t=1}^{T} S_t' V^{-1} S_t, \tag{5}$$

where $\widehat{u}_t = y_t - x_t'\widehat{\beta}$ are the OLS residuals from regressing y_t on x_t, $\widehat{\sigma}^2 = (T-K)^{-1} \sum_{t=1}^{T} \widehat{u}_t^2$, $S_t = \sum_{j=t}^{T} \widehat{u}_j x_{1j}$ and $V = T^{-1} \sum_{t=1}^{T} x_{1t} x_{1t}'$. The test can be made robust to heteroscedasticity if $\widehat{\sigma}^{-2} V^{-1}$ is replaced by V_*^{-1}, with $V_* = (T-K)^{-1} \sum_{t=1}^{T} \widehat{u}_t^2 x_t x_t'$.

This is a locally most powerful invariant test against random walk coefficients throughout the whole sample. Since we are interested in detecting end-of-sample instabilities, we propose a modification of the test that focus on breaks potentially occuring only in the last fraction of the sample $\pi = 1 - \frac{m}{T}$. The test therefore has optimal properties against the alternative hypothesis that

$$\delta_t = \begin{cases} 0 & \text{for } t = 1, ..., T - [\pi T] \\ \delta_{t-1} + \eta_t & \text{for } t = [\pi T] + 1, ..., T \end{cases}$$

where η_t is a Gaussian $iid(0, \theta\sigma^2 I_T)$ disturbance independent of x_t and u_t, with $\theta \geq 0$. The LMP statistic is

$$L(\pi) = \widehat{\sigma}^{-2} (T - [\pi T])^{-2} \sum_{t=[\pi T]+1}^{T} S_t' V^{-1} S_t, \tag{6}$$

which corresponds to (5) if $\pi = 0$.[4] Under the null hypothesis of constant coefficients, the limiting distribution can be represented as a quadratic form of k_1-dimensional Brownian bridge

$$L(\pi) \xrightarrow{d} (1 - \pi)^{-2} \int_{\pi}^{1} B_{k_1}(s)' B_{k_1}(s) ds. \tag{7}$$

[4] In a time series context, a similar statistic was proposed by Busetti and Taylor (2004) for detecting a switch from a I(0) to a I(1) process at the fraction π of the sample.

If the location of a possible parameter instability is unknown, we proceed as for the Wald-type tests using the statistics

$$\text{Sup-}L = \underset{\pi\in\Pi}{Sup}\ L(\pi) \tag{8}$$

$$\text{Exp-}L = \log \int_{\pi\in\Pi} \exp(L(\pi))\, dJ(\pi) \tag{9}$$

for $\Pi = [.05, 95]$, $[.01, .99]$, $[.75, .99]$, $[.90, .99]$, and

$$\text{Exp-}L_{LIN} = \log \int_{\pi\in\Pi} \exp(L(\pi))\, \pi d\pi. \tag{10}$$

for $\Pi = [.01, .99]$. The null limiting distributions of (8)-(10) are immediately obtained from (7) by an application of the Continuous Mapping Theorem. Asymptotic critical values are shown in table 1.

2.3 The case of a small number of end-of-sample observations

When the number of post-changepoint observations is 'small', the distribution of the F-statistic (2) cannot be approximated by a χ^2 and thus the χ^2 critical values are no longer appropriate.[5] Andrews (2003) has proposed a variant of the F test that can be used even for a very small end-of-sample size, where the critical values are obtained by a simple 'parametric subsampling' method. For the case of serially uncorrelated disturbances u_t (and $m \geq K$) the statistic is defined as

$$\mathcal{S} = \mathcal{S}_{n+1}\left(\widehat{\beta}, \widehat{\sigma}^2\right) \tag{11}$$

where $\widehat{\beta}$ is the OLS estimate of β (using all the $n+m$ observations), $\widehat{\sigma}^2$ is the usual estimate of the error variance, and for $j = 1, 2, ..., n+1$,

$$\mathcal{S}_j\left(\beta, \sigma^2\right) = \sigma^{-2}\left(Y_j(m) - X_j(m)\beta\right)'\ P_j(m)\ \left(Y_j(m) - X_j(m)\beta\right), \tag{12}$$

with $P_j(m) = X_j(m)\left[X_j(m)'X_j(m)\right]^{-1} X_j(m)'$ is the usual projection matrix, $X_j(m)$ is the $m \times K$ matrix $\left(x_j',\ x_{j+1}',\ ...,\ x_{j+m-1}'\right)'$, $Y_j(m)$ is the $m \times 1$ vector $\left(y_j,\ y_{j+1},\ ...,\ y_{j+m-1}\right)'$.

Andrews (2003) shows that for large T and m fixed the distribution function of $\mathcal{S}$ converges to the empirical distribution function of $\{\mathcal{S}_j(\beta, \sigma^2) :\ j = 1, ..., n-m+1\}$ evaluated at consistent estimators of

[5] However under Gaussian errors and strictly exogenous regressors the statistic follows an F distribution in finite samples under the null hypothesis.

β and σ^2. The critical value of the test is therefore the $1-\alpha$ sample quantile of $\{\mathcal{S}_j(\beta,\sigma^2): \ j=1,...,n-m+1\}$. In our simulations we use the estimators $\widehat{\beta}_{(n)}$ and $\widehat{\sigma}^2_{(n)}$ obtained by a single OLS regression over the stability subsample $(t=1,...,n)$.[6]

When the end-of-sample size is small the distribution of the proposed $L(\pi)$ test (6) can also be obtained by the same parametric subsampling approach. It just requires to obtain the empirical distribution function of $\left\{\mathcal{L}_j\left(\widehat{\beta}_{(n)},\widehat{\sigma}^2_{(n)}\right): \ j=1,...,n-m+1\right\}$, where, for $j=1,2,...,n+1$,

$$\mathcal{L}_j\left(\widehat{\beta}_{(n)},\widehat{\sigma}^2_{(n)}\right)=\widehat{\sigma}^{-2}_{(n)}m^{-2}\sum_{t=j}^{j+m-1}S_{t,j}\left(\widehat{\beta}_{(n)}\right)'V^{-1}S_{t,j}\left(\widehat{\beta}_{(n)}\right)$$

where $S_{t,j}\left(\widehat{\beta}_{(n)}\right)=\sum_{h=t}^{j+m-1}\left(y_h-x_h'\widehat{\beta}_{(n)}\right)x_{1h}$. We call this test $\mathcal{L}(\pi)$.[7]

3 Size and power properties of the tests

The size and power properties of the tests described in Section 2 are evaluated by means of Monte Carlo simulations in the context of simple linear regression models. The first subsection considers both cases of a one-time change in the parameters and of random walk coefficients for a static regression model. The second section looks at dynamic models, providing results for the case of a change in the persistence parameter of an autoregression. In all experiments the number of Monte Carlo replications is set to 50000.

3.1 Static regression models

The data generating process in the Monte Carlo simulations corresponds to the model (1) with $x_{1t}=(1,(-1)^t)$, $\sigma^2=1$ and where there are no other regressors x_{2t}. For the alternative hypothesis we consider both cases of one-time change and random walk coefficients. The set-up is broadly similar to the one considered in Andrews et al. (1996). We look specifically at the properties of the tests when the breakpoint occurs in the latest part of the sample, affecting the last 25%, 10%, 5% and 2% observations.

[6] For each j Andrews choses a 'leave-$[m/2]$-out' that use $n+[m/2]$ observations (i.e. leaves out $t=j,j+1,...,j+[m/2]-1$); this is obtained by looking at the size/power tradeoff of his Monte Carlo experiments. Our choice on the other hand reflects our focus for the cases of: (i) relatively large m, which discourages using observations in the second subsample; (ii) dynamic regression models where one cannot leave out central observations in the sample.

[7] A special case of this test occurs by setting $x_{1t}=1$ in the statistics; this was proposed by Andrews and Kim (2006) as a test of 'cointegration breakdown' at the end of the sample.

Tables 2 and 3 presents the empirical size of the tests for sample sizes of $T = 100$, 200 and 400 observations for both Gaussian and non-Gaussian disturbances (the latter only for $T = 200$) and tests run at 5% significance; note that the statistics reported in Table 3 are computed for a given changepoint and - in the case of subsampling - with the empirical distribution that depends on π. Consider first the Gaussian case. For $T = 100$ the size is accurate for the standard F test with a known breakpoint and the L test of Nyblom (1989). The asymptotic F-type tests tend to present smaller distorsions than the LMP type tests, which tend to be somewhat oversized; however, in all cases but one the empirical rejection frequencies do not exceed 8%. The subsampling $F(\pi_0)$ and $L(\pi_0)$, that require a "small" post-break subsample, have good size properties for $\pi_0 \geq 0.95$ but they are significantly oversized otherwise. Increasing the sample to 200 and 400 observations yields better sized tests, except for the case of the subsampling statistics (however their oversizing is still minor if $\pi_0 \geq 0.95$). For $T = 400$ nearly all asymptotic tests present rejection frequencies equal to the nominal size. In the case of non-Gaussian distributions (and $T = 200$), the tests tend to be oversized but in most cases the empirical rejection frequencies do not exceed 10%; the deterioration of the size properties is more evident for the F-type statistics.

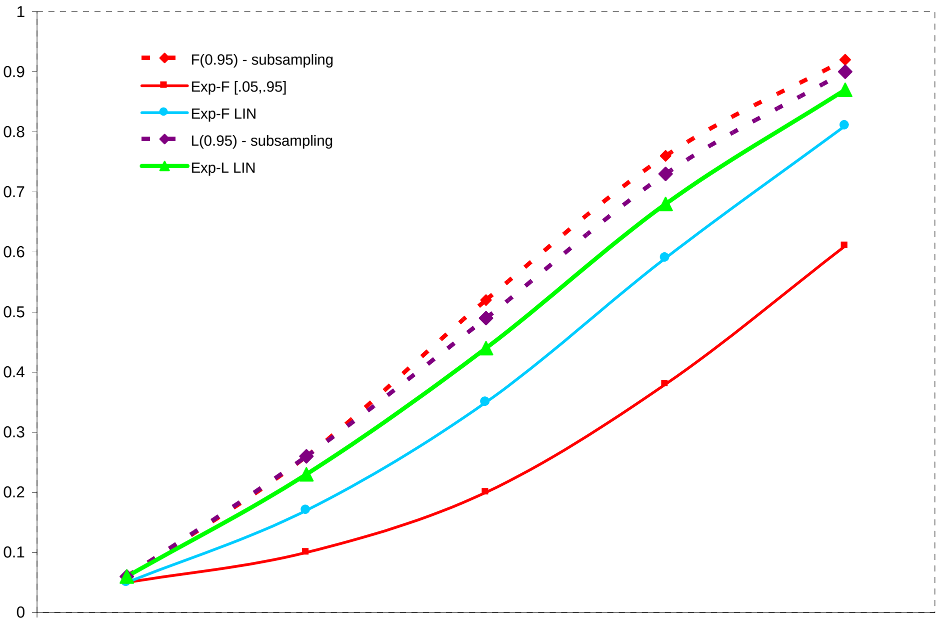
We now turn to the power of the tests under a local deviation from the null hypothesis.[8] Consider first the case of one-time change in the coefficients, where the local alternative hypothesis is $\delta_{t,T} = \delta/\sqrt{T}\mathbf{i}$ for all $t = n+1, n+2, ..., n+m$, and i is a two-dimesional vector of ones. Table 4 contains rejection frequencies for $\delta = 4.8,\ 7.2,\ 9.6,\ 12$ that yields the power of the tests (not size-adjusted).

If the changepoint is known the Wald F-test has optimal properties and it therefore presents the highest rejection frequencies (because of the oversizing, in a few cases other tests have slightly higher rejection frequencies); for $\pi_0 \geq 0.95$ the subsampling version of the F-test has very similar size and power properties as the asymptotic test. It is however intersting to observe that as $\pi_0 \to 1$ the Wald test $F(\pi_0)$ behaves very similarly to the LMP test $L(\pi_0)$.

If the changepoint is unknown, we first confirm the result of Andrews et al. (1996) that the Exp-F test has higher power than the Sup-F test; the same is true for the comparison between Sup-L and Exp-L. However, and interestingly, the rejection frequencies of the Exp-L (Sup–L) tests appear generally higher than those of the Exp-F (Sup-F). For example

[8] In these simulations the sample size is $T = 200$, but the rejection frequencies provided are not affected in principles by the sample size since they represent an approximation of the local asymptotic power of the tests.

Figure 1: Power of selected tests against a one-time shift in the coefficients at $\pi = 0.95$.

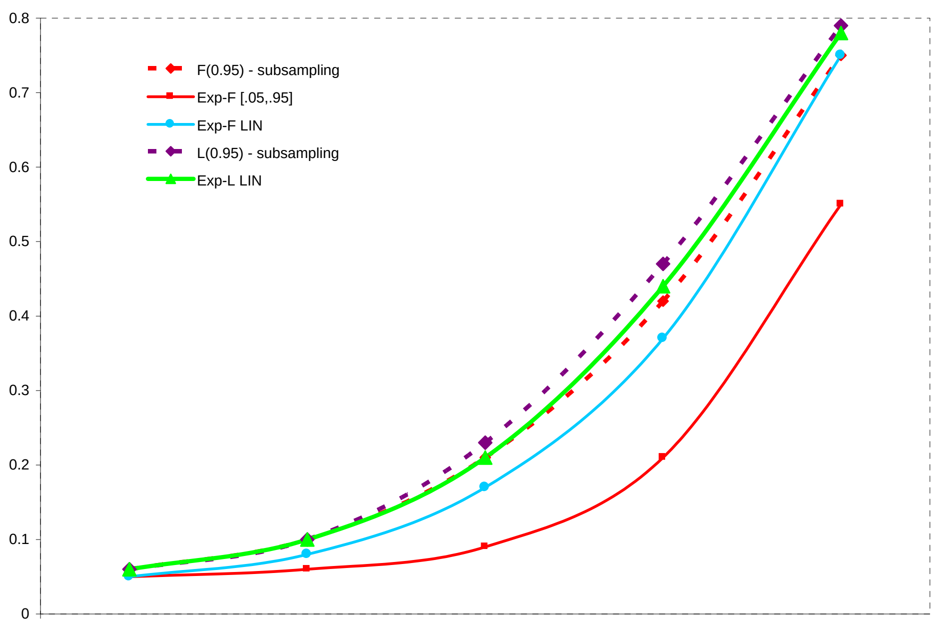


for $\delta = 9.6$ and $\pi_0 = 0.95$, the rejection frequency of Exp-L over [.01,.99] is 0.63 against 0.44 of Exp-F; these two figures become 0.70 and 0.60 for tests computed over the interval [.75,.99] of possible breakpoints. The properties of Exp-F_{LIN} are very similar to that of Exp-F when the latter is computed over $\Pi = [.75, .99]$; both tests are however dominated by Exp-L_{LIN} and Exp-L over $\Pi = [.75, .99]$. For late changepoints, when $0.95 \leq \pi_0 \leq 0.98$, the highest rejection frequencies are displayed by Exp-L over $\Pi = [.90, .99]$, that however suffers from non negligible oversizing when $T = 100$. The Exp-L_{LIN} is on balance a better option in this case.

Figure 1 summarizes the main findings in terms of power under the alternative hypothesis of a one-time shift in the coefficcients occuring in the last 5 per cent of the sample, $\pi = 0.95$.

Table 5 reports the power properties of the tests against the case of random walk coefficients; specifically, the local alternative hypothesis is that $\delta_t = \delta_{t-1} + \eta_t$ for $t = n+1, ..., n+m$, where η_t is i.i.d. $N(0, \omega_T^2)$, $\omega_T = q/T$; simulation results are presented for values of $q = 0, .15, .3, .5, 1$. If the changepoint is known, as expected the subsampling version of the LMP test achieves the highest power and it is preferable to the

Figure 2: Power of selected tests against random walk coefficients starting at $\pi = 0.95$.



subsampling F-test. For the case of unknown changepoint, the results are qualitatively similar to the one reported in the previous table, with the LMP-type tests displaying higher power than the Wald-type tests. The main findings for $\pi = 0.95$ are summarised graphically in Figure 2.

Overall, our simulations suggest that - for the case of unknown changepoint occurring towards the end of the sample - good choices are the Exp-L_{LIN} test and the Exp-L computed over $\Pi = [.75, .99]$, as their power is close to that of the optimal Wald and LMP statistics under both cases of one-time parameter shift and of random walk coefficients respectively; these tests are however slightly oversized when the sample size tends to be small. Among the two tests, unreported simulations show that Exp-L_{LIN} is preferable when changepoints occur earlier in the sample.

3.2 Dynamic regression models

For dynamic regression models it is of interest to evaluate the properties of the tests when there is a change in the degree of persistence in the data. Here we consider a simple AR(1) process and evaluate the tests against a one-time change in the autoregressive coefficient. The data generating process corresponds to the model (1) with $x_{1t} = y_{t-1}$, $x_{2t} = 1$, $\sigma^2 = 1$; we consider a one time change in both direction of lower and higher persistence, $\delta_t = -0.4$ and 0.4 for $t = n+1, ..., n+m$, starting from $\beta_1 = 0.5$. Table 6 provide the rejection frequencies of the tests for a sample size of $T = 400$ observations. The Wald-type tests display once again very good size properties, while the empirical size of the LMP-type tests tend to be slightly higher than the nominal 5% even for $T = 400$. For all tests the power of the tests tends to be much higher for an increase than a decrease of persistence. More interestingly, the Wald-type tests appear significantly more powerful than the LMP-type of test when there is a decrease in persistence ($\rho = 0.1$), while the opposite is true for $\rho = 0.9$. For example for $\pi_0 = 0.95$ the rejection frequencies of Exp-F_{LIN} (Exp-L_{LIN}) are 0.22 (0.13) for $\rho = 0.1$ and 0.56 (0.73) for $\rho = 0.9$.

4 Empirical illustrations

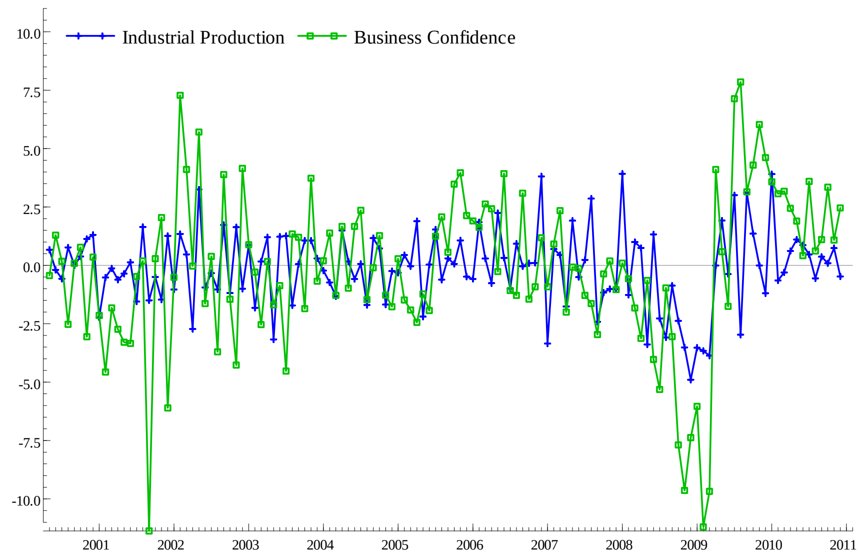
We use the tests to detect possible instabilities in two simple 'nowcasting' regression models for Italian output. Nowcasting quarterly GDP is usally based on indicators available more timely and/or with higher frequency. One well-known good predictor for GDP is industrial production. However the monthly data for industrial production are only available with a substantial lag, which requires for a further predictive model to be constructed, based on 'qualitative' indicators coming from surveys that are often available before the end of the same month.

Here we consider two simple models, one for quarterly GDP and the other for monthly industrial production, which can be used in conjunction for the purpose of nowcasting Italian GDP growth. Figure 1 shows the monthly series of Italian industrial production and that of a business confidence indicator over the period 2000-2010 (in terms of percentage growth rates). The question is whether the association between a sentiment indicator and the corresponding 'hard data' breaks down at time of crisis, as during the profound recession of 2008-2009. We capture the association between (the log of) industrial production, y_t, and the (log of the) confidence indicator, x_t, by the simple linear regression

$$\Delta y_t = \alpha_0 + \alpha_1 \Delta y_{t-1} + \alpha_2 \Delta x_t, \tag{13}$$

where Δ is the first difference operator. We investigate end-of-sample instability by estimating this model for samples of different lengths. The shortest sample consists of 98 observations, ending in June 2008 (denoted as 2008.H1, with H1 indicating the 1st half of the year); then we add 6 observations at time and recompute the tests with samples that end at

Figure 3: Monthly industrial production and business confidence in Italy, 2000-2010

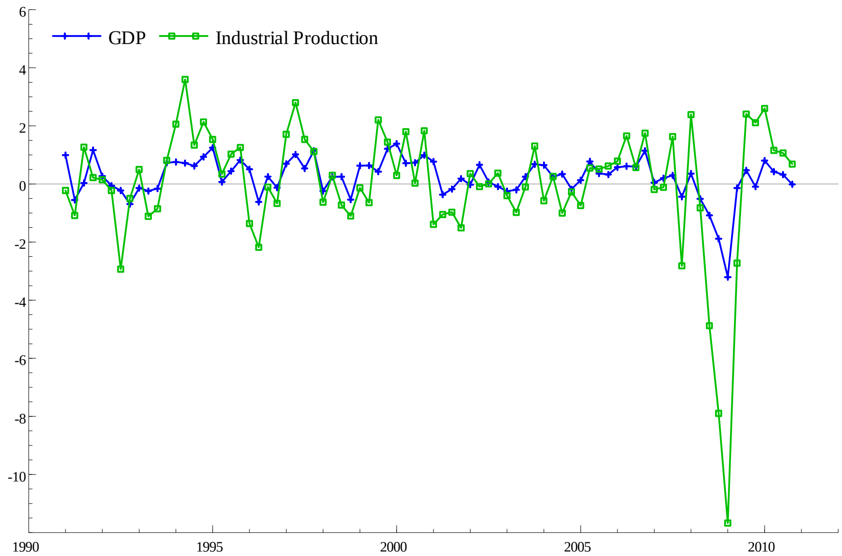


2008.H2, 2009.H1, 2009.H2, 2010.H1, 2010.H2. The results are reported in Table 7, where the tests are computed allowing for instabilities in all three coefficients $\alpha_0,\ \alpha_1,\ \alpha_2$. The table shows that the model (13) appears stable if it is estimated using data up to the first half of 2008, before the financial crisis became acute (the bankruptcy of Lehmann Brothers occurred in September 2008). Thereafter, using data up to the end of 2008 and later, nearly all tests strongly reject the null hypothesis of stability. Note that the evidence provided by both the Wald-type and the LMP-type tests is very similar.

The same exercise is then carried out for the association between GDP and (quarterly) industrial production. Figure 2 shows the percentage growth rates of these two series over the period 1991-2010. Table 8 reports the results of the tests for the same linear regression model (13) estimated with different end-points. Here, the Wald-type tests almost never reject the null hypothesis of stability while the LMP-type tests display a strong tendency to reject, particularly when the data of 2009 are included in the sample. Indeed the signs of instabilities begin earlier.[9] These results appear coherent with the simulation evidence reported in the previous section that showed generally higher rejection frequencies

[9] This may be related to the fact that the recessive phase of the Italian industrial sector started at the beginning of 2007 while GDP growth turned negative only in last quarter of that year.

Figure 4: Quarterly GDP and industrial production in Italy, 1991-2010.



for the LMP-type tests, despite some oversizing in small samples. For this specific example, a rejection of the hypothesis of stability seems a plausible outcome.[10]

Overall, the two empirical illustrations convey the message that model-based predictions should be interpreted with caution in the presence of unusually large fluctuations of the indicators towards the end of the sample; in these cases adding a dose of forecaster's judgement would be a wise option to choose.

5 Conclusions

The paper has investigated the properties of several tests aimed at detecting instabilities that may occur towards the end of the sample. Tests constructed in terms of LMP statistics appear in general more powerful than those based on Wald statistics; the latter however possess better size properties. Overall, a LMP-type test that gives increasing weight to possible changepoints along the sample appears to be a good choice against both alternative hypotheses of one-time parameter shift and of random walk coefficients. Its power is in fact quite close to that of the optimal tests based on knowing the end-of-sample changepoint in

[10] For both models the heteroskedasticity robust version of the LMP-type tests, as described in Section 2.2, provides very similar results to the standard version; details are available upon request.

advance.

The practical usefulness of these tests has been demonstrated by applying them to nowcasting regression models for industrial production and GDP in Italy.

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Table 1. Critical values of the Wald-type and LMP-type tests.

		k=1			k=2			k=3			k=4			k=5		
		0.10	0.05	0.01	0.10	0.05	0.01	0.10	0.05	0.01	0.10	0.05	0.01	0.10	0.05	0.01
Test	Π															
Sup-F	[.05,.95]	8.206	9.789	13.157	5.593	6.436	8.235	4.532	5.127	6.438	3.915	4.405	5.450	3.540	3.948	4.826
	[.01,.99]	9.041	10.639	14.152	6.065	6.907	8.696	4.865	5.463	6.751	4.189	4.662	5.659	3.762	4.158	5.000
	[.75,.99]	7.152	8.682	11.999	4.972	5.829	7.647	4.082	4.699	6.070	3.574	4.052	5.104	3.249	3.653	4.516
	[.90,.99]	6.479	7.978	11.402	4.584	5.432	7.264	3.786	4.402	5.729	3.337	3.816	4.854	3.038	3.446	4.309
Exp-F	[.05,.95]	1.513	2.035	3.356	2.635	3.281	4.734	3.611	4.308	5.939	4.496	5.270	7.050	5.356	6.202	8.155
	[.01,.99]	1.523	2.048	3.341	2.668	3.296	4.739	3.647	4.357	5.953	4.555	5.307	7.056	5.419	6.263	8.176
	[.75,.99]	1.483	2.016	3.346	2.542	3.194	4.701	3.487	4.249	5.958	4.344	5.157	6.967	5.185	6.054	7.977
	[.90,.99]	1.461	2.026	3.394	2.514	3.180	4.722	3.423	4.196	5.923	4.263	5.066	6.885	5.073	5.927	7.854
Exp-F-LIN	[.01,.99]	0.748	1.047	1.892	1.421	1.839	2.912	2.086	2.610	3.902	2.731	3.331	4.770	3.398	4.082	5.677
L(.75)		0.976	1.319	2.158	1.641	2.099	3.335	2.249	2.748	3.940	2.887	3.497	4.737	3.464	4.119	5.401
L(.90)		1.097	1.511	2.539	1.854	2.365	3.486	2.578	3.160	4.347	3.303	3.878	5.131	3.940	4.496	6.001
Sup-L	[.05,.95]	1.623	2.088	3.117	2.533	3.116	4.519	3.335	3.900	5.308	4.115	4.785	6.134	4.777	5.399	6.939
	[.01,.99]	1.949	2.489	3.596	2.971	3.531	4.917	3.798	4.409	5.797	4.600	5.281	6.644	5.352	6.145	7.466
	[.75,.99]	1.929	2.473	3.596	2.940	3.495	4.911	3.781	4.383	5.780	4.571	5.277	6.644	5.342	6.129	7.466
	[.90,.99]	1.809	2.367	3.441	2.842	3.388	4.813	3.662	4.235	5.656	4.434	5.144	6.593	5.229	6.042	7.393
Exp-L	[.05,.95]	0.776	1.028	1.710	1.343	1.668	2.671	1.898	2.333	3.359	2.527	2.980	3.997	3.033	3.558	4.742
	[.01,.99]	0.774	1.029	1.696	1.363	1.693	2.726	1.940	2.367	3.411	2.581	3.063	4.114	3.128	3.633	4.886
	[.75,.99]	1.081	1.448	2.326	1.866	2.341	3.483	2.565	3.100	4.220	3.308	3.886	5.238	3.980	4.535	5.912
	[.90,.99]	1.124	1.521	2.546	2.002	2.522	3.734	2.726	3.279	4.532	3.438	4.065	5.407	4.156	4.830	6.163
Exp-L-LIN	[.01,.99]	0.494	0.668	1.172	0.915	1.214	2.005	1.368	1.725	2.561	1.893	2.340	3.396	2.421	2.837	4.011

Table 2. Empirical size of the tests for the static regression model under Gaussianity.

Test	Π	*Gaussian errors* T=100	T=200	T=400	*t(3)* T=200	χ2 T=200
Sup-F	[.05,.95]	.04	.04	.05	.08	.07
	[.01,.99]	.04	.04	.04	.12	.11
	[.75,.99]	.03	.03	.04	.09	.08
	[.90,.99]	.02	.03	.04	.08	.08
Exp-F	[.05,.95]	.06	.05	.05	.08	.07
	[.01,.99]	.06	.05	.05	.13	.11
	[.75,.99]	.06	.05	.06	.10	.09
	[.90,.99]	.05	.05	.05	.10	.09
Exp-F-LIN	[.01,.99]	.06	.05	.06	.10	.09
L(0)		.05	.05	.05	.05	.04
L(.75)		.06	.06	.06	.07	.06
L(.90)		.11	.09	.09	.11	.10
Sup-L	[.05,.95]	.06	.05	.05	.08	.07
	[.01,.99]	.08	.07	.06	.10	.10
	[.75,.99]	.07	.07	.06	.10	.10
	[.90,.99]	.08	.07	.06	.10	.10
Exp-L	[.05,.95]	.06	.06	.06	.07	.07
	[.01,.99]	.07	.06	.05	.09	.08
	[.75,.99]	.07	.06	.05	.10	.09
	[.90,.99]	.09	.07	.06	.10	.09
Exp-L-LIN	[.01,.99]	.07	.06	.05	.09	.09

Table 3. Empirical size of the standard F-test and of the subsampling-based tests for the static regression model for different error distributions

	Gaussian errors												*t(3) errors*				*$\chi 2$ errors*			
	T=100				T=200				T=400				T=200				T=200			
π	0.75	0.90	0.95	0.98	0.75	0.90	0.95	0.98	0.75	0.90	0.95	0.98	0.75	0.90	0.95	0.98	0.75	0.90	0.95	0.98
Test																				
F (π_0)	.05	.05	.05	.06	.05	.05	.05	.05	.05	.05	.05	.05	.05	.07	.07	.07	.05	.05	.06	.07
F (π_0) - subsamp	.17	.08	.06	.06	.17	.08	.06	.06	.17	.08	.07	.05	.16	.08	.06	.06	.17	.08	.06	.06
L (π_0) - subsamp	.15	.08	.06	.06	.15	.07	.06	.05	.15	.08	.06	.05	.14	.07	.06	.06	.15	.07	.06	.05

Table 4. Empirical rejection frequencies of the tests for the static regression model against a one time change in the coefficient at the fraction p0 of the sample size (T=200) under Gaussianity; for c>0 the table provides estimates of the asymptotic local power functions.*

			δ=4.8				δ=7.2				δ=9.6				δ=12			
		π_0	0.75	0.90	0.95	0.98	0.75	0.90	0.95	0.98	0.75	0.90	0.95	0.98	0.75	0.90	0.95	0.98
Test	Π																	
F (π_0)			.75	.43	.25	.13	.98	.79	.50	.24	1.00	.96	.76	.38	1.00	1.00	.92	.56
F (π_0) - subsamp			.83	.47	.26	.14	.99	.79	.52	.24	1.00	.96	.76	.39	1.00	.99	.92	.56
F (.95) - subsamp			.40	.29	.26	.08	.56	.51	.52	.11	.72	.73	.76	.16	.84	.89	.92	.24
Sup-F	[.05,.95]		.50	.22	.10	.05	.90	.51	.21	.06	1.00	.83	.43	.07	1.00	.97	.68	.09
	[.01,.99]		.45	.19	.09	.05	.88	.47	.21	.07	.99	.79	.42	.12	1.00	.96	.67	.21
	[.75,.99]		.50	.26	.13	.06	.90	.58	.30	.10	1.00	.87	.54	.19	1.00	.98	.77	.31
	[.90,.99]		.15	.24	.13	.06	.34	.57	.32	.12	.60	.86	.57	.21	.83	.98	.80	.34
Exp-F	[.05,.95]		.58	.24	.10	.06	.93	.53	.20	.07	1.00	.83	.38	.08	1.00	.97	.61	.10
	[.01,.99]		.57	.24	.11	.07	.92	.53	.23	.09	1.00	.83	.44	.13	1.00	.97	.68	.20
	[.75,.99]		.60	.35	.18	.08	.93	.69	.36	.13	1.00	.92	.60	.21	1.00	.99	.82	.33
	[.90,.99]		.22	.33	.22	.10	.45	.66	.44	.17	.71	.91	.69	.28	.89	.99	.88	.42
Exp-F-LIN	[.01,.99]		.62	.33	.17	.08	.94	.66	.35	.12	1.00	.91	.59	.21	1.00	.99	.81	.33
L(0)			.50	.13	.07	.05	.88	.25	.09	.05	.99	.43	.13	.06	1.00	.65	.18	.06
L(.75)			.66	.33	.13	.07	.95	.64	.23	.08	1.00	.88	.38	.10	1.00	.98	.56	.13
L(.90)			.36	.49	.29	.13	.63	.80	.53	.19	.84	.96	.76	.25	.95	1.00	.91	.35
L (π_0) - subsamp			.74	.42	.26	.15	.96	.73	.49	.26	1.00	.93	.73	.42	1.00	.99	.90	.60
L (.95) - subsamp			.38	.29	.26	.06	.54	.50	.49	.12	.69	.72	.73	.21	.81	.88	.90	.33
Sup-L	[.05,.95]		.51	.36	.23	.09	.90	.70	.46	.14	1.00	.92	.71	.22	1.00	.99	.89	.33
	[.01,.99]		.43	.32	.23	.15	.85	.63	.44	.27	.99	.89	.68	.42	1.00	.98	.87	.60
	[.75,.99]		.39	.31	.23	.15	.81	.63	.44	.27	.98	.89	.68	.42	1.00	.98	.87	.60
	[.90,.99]		.21	.30	.24	.16	.41	.60	.46	.28	.65	.87	.70	.44	.85	.98	.88	.61
Exp-L	[.05,.95]		.64	.36	.17	.08	.95	.69	.35	.10	1.00	.92	.59	.15	1.00	.99	.80	.21
	[.01,.99]		.61	.35	.20	.10	.93	.68	.39	.16	1.00	.91	.63	.27	1.00	.99	.84	.41
	[.75,.99]		.44	.39	.24	.12	.82	.72	.46	.20	.98	.93	.70	.33	1.00	.99	.88	.48
	[.90,.99]		.24	.33	.27	.15	.44	.62	.51	.26	.66	.87	.75	.40	.85	.97	.91	.57
Exp-L-LIN	[.01,.99]		.54	.37	.23	.11	.90	.70	.44	.20	.99	.92	.68	.32	1.00	.99	.87	.47

* π_0 is the true breakpoint location, while δ represents the distance from the null hypothesis

Table 5. Empirical rejection frequencies of the tests for the static regression model against random walk coefficients at the fraction p0 of the sample size (T=200) under Gaussianity; for q>0 the table provides estimates of the asymptotic local power functions. *

			q=0.15				q=0.3				q=0.5				q=1			
		π_0	0.75	0.90	0.95	0.98	0.75	0.90	0.95	0.98	0.75	0.90	0.95	0.98	0.75	0.90	0.95	0.98
Test	Π																	
F (π_0)			.52	.18	.09	.06	.82	.46	.20	.08	.92	.71	.41	.14	.97	.91	.74	.36
F (π_0) - subsamp			.63	.22	.10	.06	.86	.49	.21	.09	.94	.72	.42	.14	.98	.91	.75	.37
F (.95) - subsamp			.55	.23	.10	.05	.81	.50	.21	.06	.91	.74	.42	.08	.96	.91	.75	.17
Sup-F	[.05,.95]		.48	.11	.05	.04	.84	.37	.09	.05	.95	.65	.22	.05	.99	.90	.58	.07
	[.01,.99]		.45	.10	.05	.04	.83	.36	.10	.04	.95	.66	.27	.06	.99	.91	.68	.18
	[.75,.99]		.51	.13	.06	.04	.86	.43	.14	.05	.96	.71	.34	.07	1.00	.93	.73	.24
	[.90,.99]		.35	.13	.06	.03	.73	.43	.15	.05	.88	.72	.36	.08	.96	.94	.75	.26
Exp-F	[.05,.95]		.52	.12	.06	.05	.85	.37	.09	.06	.95	.65	.21	.06	.99	.89	.55	.08
	[.01,.99]		.52	.13	.07	.05	.85	.39	.11	.06	.95	.67	.28	.07	1.00	.92	.67	.18
	[.75,.99]		.59	.19	.08	.06	.89	.49	.17	.07	.97	.75	.38	.09	1.00	.94	.75	.26
	[.90,.99]		.43	.20	.09	.06	.77	.51	.21	.07	.91	.77	.43	.11	.97	.95	.79	.31
Exp-F-LIN	[.01,.99]		.57	.18	.08	.06	.89	.47	.17	.07	.97	.74	.37	.09	1.00	.94	.75	.25
L(0)			.41	.07	.05	.05	.76	.17	.06	.05	.89	.38	.09	.05	.97	.71	.23	.06
L(.75)			.60	.16	.07	.06	.88	.41	.11	.06	.96	.67	.22	.07	.99	.89	.55	.11
L(.90)			.53	.28	.13	.09	.82	.58	.25	.11	.93	.80	.46	.14	.97	.95	.78	.26
L (π_0) - subsamp			.68	.23	.10	.06	.91	.53	.23	.09	.97	.77	.47	.15	1.00	.94	.79	.39
L (.95) - subsamp			.53	.23	.10	.03	.78	.50	.23	.04	.90	.74	.47	.07	.96	.92	.79	.22
Sup-L	[.05,.95]		.55	.20	.09	.06	.87	.51	.20	.07	.96	.76	.42	.09	1.00	.94	.76	.23
	[.01,.99]		.51	.20	.11	.07	.85	.50	.23	.10	.96	.76	.45	.16	1.00	.95	.80	.39
	[.75,.99]		.50	.20	.11	.07	.85	.50	.23	.10	.95	.76	.45	.16	1.00	.95	.80	.39
	[.90,.99]		.40	.20	.11	.08	.75	.50	.24	.11	.90	.76	.47	.16	.97	.95	.81	.40
Exp-L	[.05,.95]		.59	.18	.08	.06	.88	.47	.16	.06	.96	.73	.33	.08	1.00	.93	.69	.16
	[.01,.99]		.58	.19	.08	.06	.88	.48	.18	.07	.97	.75	.40	.10	1.00	.94	.76	.28
	[.75,.99]		.55	.22	.10	.07	.87	.52	.22	.08	.96	.77	.44	.13	1.00	.95	.79	.32
	[.90,.99]		.42	.22	.12	.08	.76	.52	.26	.10	.90	.77	.49	.16	.97	.95	.82	.38
Exp-L-LIN	[.01,.99]		.57	.21	.10	.06	.88	.51	.21	.08	.96	.77	.44	.12	1.00	.95	.78	.31

* π_0 is the true breakpoint location, while q represents the distance from the null hypothesis

Table 6. Empirical rejection frequencies of the tests for the static regression model against a one time change in the persistence coefficient at the fraction p0 of the sample size (T=400). *

			ρ=0.5				ρ=0.1				ρ=0.9			
			size of the tests				decrease in persistence				increase in persistence			
		π_0	0.75	0.90	0.95	0.98	0.75	0.90	0.95	0.98	0.75	0.90	0.95	0.98
Test	Π													
F (π_0)			.05	.05	.05	.05	.91	.57	.32	.14	.99	.86	.62	.35
F (π_0) - subsamp			.16	.08	.06	.05	.95	.61	.33	.14	.99	.84	.61	.34
F (.95) - subsamp			.24	.09	.06	.05	.47	.35	.33	.10	.53	.59	.61	.25
Sup-F	[.05,.95]		.05	.05	.05	.05	.71	.33	.15	.06	.97	.73	.45	.15
	[.01,.99]		.04	.04	.04	.04	.67	.28	.14	.06	.96	.71	.46	.22
	[.75,.99]		.05	.05	.05	.05	.70	.38	.19	.08	.97	.77	.53	.27
	[.90,.99]		.04	.04	.04	.04	.23	.33	.20	.09	.46	.77	.55	.29
Exp-F	[.05,.95]		.05	.05	.05	.05	.76	.32	.13	.06	.98	.75	.46	.16
	[.01,.99]		.05	.05	.05	.05	.75	.32	.15	.07	.98	.76	.48	.21
	[.75,.99]		.05	.05	.05	.05	.78	.46	.22	.09	.98	.83	.57	.27
	[.90,.99]		.05	.05	.05	.05	.30	.41	.26	.11	.50	.81	.61	.31
Exp-F-LIN	[.01,.99]		.05	.05	.05	.05	.80	.43	.22	.09	.98	.82	.56	.27
L(0)			.04	.04	.04	.04	.60	.14	.06	.05	.98	.71	.40	.13
L(.75)			.05	.05	.05	.05	.70	.29	.09	.05	.99	.88	.61	.27
L(.90)			.08	.08	.08	.08	.28	.36	.20	.08	.69	.91	.75	.42
L (π_0) - subsamp			.16	.07	.05	.05	.78	.29	.12	.05	.99	.88	.70	.43
L (.95) - subsamp			.18	.08	.05	.04	.26	.15	.12	.04	.61	.69	.70	.39
Sup-L	[.05,.95]		.07	.07	.07	.07	.54	.25	.13	.06	.98	.89	.73	.41
	[.01,.99]		.08	.08	.08	.08	.44	.20	.12	.08	.98	.89	.74	.49
	[.75,.99]		.08	.08	.08	.08	.36	.21	.12	.08	.96	.89	.74	.49
	[.90,.99]		.09	.09	.09	.09	.13	.18	.12	.08	.63	.87	.74	.49
Exp-L	[.05,.95]		.06	.06	.06	.06	.70	.30	.12	.05	.99	.89	.69	.35
	[.01,.99]		.07	.07	.07	.07	.66	.27	.12	.07	.99	.89	.71	.43
	[.75,.99]		.07	.07	.07	.07	.40	.28	.13	.07	.94	.90	.73	.45
	[.90,.99]		.08	.08	.08	.08	.14	.19	.15	.08	.61	.85	.75	.48
Exp-L-LIN	[.01,.99]		.07	.07	.07	.07	.55	.27	.13	.07	.98	.90	.73	.45

* π_0 is the true breakpoint location, while q represents the distance from the null hypothesis

Table 7. End-of-sample tests for the Industrial Production equation and different end-dates of the sample; *=reject at 10%, **=reject at 5%, ***=reject at 1%.

		End sample	2008.H1	2008.H2	2009.H1	2009.H2	2010.H1	2010.H2
Test	Π	n. obs.	98	104	110	116	122	128
F(.95) - subsampling			-	***	-	**	*	-
Sup-F	[.05,.95]		-	***	***	***	***	***
	[.01,.99]		-	***	***	***	***	***
	[.75,.99]		-	***	***	***	***	***
	[.90,.99]		-	***	***	-	-	-
Exp-F	[.05,.95]		-	***	***	***	***	***
	[.01,.99]		-	***	***	***	***	***
	[.75,.99]		-	***	***	***	***	***
	[.90,.99]		-	***	***	-	-	-
Exp-F-LIN	[.01,.99]		-	***	***	***	***	***
L(.95) - subsampling			-	***	***	*	-	-
Sup-L	[.05,.95]		-	***	***	***	***	**
	[.01,.99]		-	***	***	***	***	**
	[.75,.99]		-	***	***	***	***	*
	[.90,.99]		-	***	***	***	-	-
Exp-L	[.05,.95]		-	***	***	***	***	***
	[.01,.99]		-	***	***	***	***	***
	[.75,.99]		-	***	***	***	***	-
	[.90,.99]		-	***	***	***	-	-
Exp-L-LIN	[.01,.99]		-	***	***	***	***	*

Table 8. End-of-sample tests for the GDP equation and different end-dates of the sample; *=reject at 10%, **=reject at 5%, ***=reject at 1%.

		End sample	2008.H1	2008.H2	2009.H1	2009.H2	2010.H1	2010.H2
Test	Π	n. obs.	70	72	74	76	78	80
F(.95) - subsampling			-	-	-	*	-	-
Sup-F	[.05,.95]		-	-	-	-	-	-
	[.01,.99]		-	-	-	-	-	-
	[.75,.99]		-	-	-	-	-	-
	[.90,.99]		-	-	-	-	-	-
Exp-F	[.05,.95]		-	-	-	-	-	-
	[.01,.99]		-	-	-	-	-	-
	[.75,.99]		-	-	-	-	-	-
	[.90,.99]		-	-	-	-	-	-
Exp-F-LIN	[.01,.99]		-	-	-	-	-	-
L(.95) - subsampling			*	-	***	***	*	-
Sup-L	[.05,.95]		-	-	***	***	*	*
	[.01,.99]		***	-	***	***	**	-
	[.75,.99]		***	-	***	***	**	*
	[.90,.99]		***	-	***	***	**	*
Exp-L	[.05,.95]		-	-	***	*	-	-
	[.01,.99]		**	-	***	***	-	-
	[.75,.99]		**	-	***	***	*	-
	[.90,.99]		**	-	***	***	**	*
Exp-L-LIN	[.01,.99]		**	-	***	***	*	-

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