Journal of Econometrics 185 (2015) 196–215

Contents lists available at ScienceDirect

Journal of Econometrics

journal homepage: www.elsevier.com/locate/jeconom

Modeling and testing smooth structural changes with endogenous regressors

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ARTICLE INFO

Article history:
Received 1 July 2013
Received in revised form
7 May 2014
Accepted 12 October 2014
Available online 18 November 2014

JEL classification:
C1
C4
E0

Keywords:
Endogeneity
Instrumental variables
Kernel
Local linear estimation
Model stability
Nonparametric regression
Smooth structural change

ABSTRACT

Modeling and detecting parameter stability of econometric models is a long standing problem. Most existing estimation and testing methods are designed for models without endogeneity. Little attention has been paid to models with endogeneous regressors, which may arise in many scenarios in economics. In this paper, we first consider a time-varying coefficient time series model with potential time-varying endogeneity. A local linear two stage least squared estimation is developed to estimate coefficient functions. The consistency and asymptotic normality of the estimator are derived. Furthermore, a nonparametric test is proposed to check smooth structural changes as well as abrupt structural breaks with possibly unknown change points in regression models with potential endogeneity. The idea is to compare the fitted values of the unrestricted nonparametric time-varying coefficient model and the restricted constant parameter model. The test has an asymptotic $N(0, 1)$ distribution and does not require any prior information about the alternatives. A simulation study highlights the merits of the proposed estimator and test. In an application, we estimate the New Keynesian Phillips Curve for the US nonparametrically and find strong evidence against its stability.

1. Introduction

Modeling and detecting structural changes in economic relationships has been a long standing problem in econometrics. It is particularly relevant for time series over a long time horizon since the underlying economic mechanism is likely to be disturbed by various factors such as preference changes, institutional changes and technological progress. The prevalence of structural instability in macroeconomic and financial time series relations has indeed been confirmed by numerous empirical studies. For example, Stock and Watson (1996) test 76 representative US monthly postwar macroeconomic time series and find substantial instability in a significant fraction of the univariate and bivariate autoregressive models. In investigating labor productivity in the US manufacturing/durables sector, Hansen (2001) identifies strong evidence of a structural break sometime between 1992 and 1996, and weaker evidence of a structural break in the 1960s and the early 1980s. Ang and Kristensen (2012) and Li and Yang (2012) find significant time-variation in factor loadings when they test conditional capital asset pricing models.

Previous works for estimating and detecting structural changes in time series econometrics mainly focus on abrupt structural breaks. Recently, smooth structural changes have gained increasing attention and some time-varying time series models have appeared as novel tools to capture the evolutionary behavior of economic time series. Among them, a nonparametric time-varying parameter time series model has attracted great interest. It is first introduced by Robinson (1989, 1991) and further studied by Orbe et al. (2000, 2005, 2006), Cai (2007), Chen and Hong (2012), Kristensen (2012) and Zhang and Wu (2012). One advantage of this nonparametric time-varying parameter model is that little restriction is imposed on the functional forms of both time-varying intercept and slope, except for the condition that they evolve with time smoothly. Despite the success of this class of time-varying parameter model, the maintained assumption all above papers impose is that all explanatory variables are exogenous or predetermined. Those methods are not applicable to many macroeconometric models where regressors are correlated with errors.

It is well known that endogeneity can arise from many different sources such as simultaneous equations, measurement errors, omitted variables, etc. All these are relevant in time series

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http://dx.doi.org/10.1016/j.jeconom.2014.10.012
0304-4076/

regression. For example, the new Keynesian Phillips curve (NKPC) is a forward-looking model of inflation dynamics, where shortrun dynamics in inflation is driven by the expected discounted stream of real marginal costs (see, e.g. Fuhrer and Moore, 1995; Gali and Gertler, 1999; Zhang et al., 2008). In this model, the future/forecasted inflation rate and the output gap/marginal cost are endogenous variables, which are correlated with the regression error, namely, the inflation surprise. Another related example is the Taylor rule, which stipulates how the fed fund rate responds to inflation rate and output. Since the seminal work by Taylor (1993), various versions of the backward-looking or forward-looking Taylor rule for the US monetary policy have been estimated. (See, e.g. Clarida et al., 2000; Kim and Nelson, 2006; Orphanides, 2004.) Similar to the NKPC, endogeneity is unavoidable since the forecast error is correlated with the forecasted inflation and the output. A third example is the arbitrage pricing theory, where the expected return of financial assets is modeled as a linear function of some macro factors (Chen et al., 1986). It has been documented in the literature that macro factors contain large measurement errors (see, e.g. Chen et al., 1986; Connor and Korajczyk, 1986, 1991; Ferson and Harvey, 1999), which would lead to the endogeneity problem.

This paper develops a two-stage local linear (2SLL) estimator for time-varying models with endogeneous regressors. The first step is to estimate a time-varying reduced form of regression model which allows for time-varying correlation between endogenous variables and instruments. The second step is a local linear regression using the projected endogeneous variables as regressors. This estimation can be regarded as a generalization of two-stage least squared (2SLS) from parametric models to nonparametric models. The difficulty of this issue lies in the fact that some of the covariates in the second stage are not directly observed but have themselves been estimated in the first nonparametric regression. We establish the consistency and asymptotic normality of the 2SLL estimator. Interestingly, similar to the 2SLS estimator, under certain regularity conditions and bandwidth conditions, the 2SLL estimator can be viewed as a LL estimator of the second stage regression, where the projection of the endogeneous variable is replaced by its probability limit. As a special case, a time-varying model with a stable reduced form is also studied. The simple LS estimation of the first stage has a faster convergence rate and hence has no impact on the second stage LL estimation asymptotically.

Furthermore, we develop a Wald-type test for structural changes in models with endogeneous regressors, which can be viewed as a generalization of Hausman's (1978) test from the parametric framework to the nonparametric framework. Chen and Hong (2012) propose the generalized Hausman's (1978) test for structural changes of a linear regression model, where the imposed orthogonality condition rules out endogeneous regressors. The current paper fills the gap. With the first stage nonparametric estimation, the theoretical derivation of the test for models with endogeneity is much more involved. And unlike Chen and Hong (2012), we remove the stationarity assumption and thus allow for covariates to be some local stationary processes. In addition, we remove the martingale difference sequence (m.d.s.) assumption so that models with serially correlated innovations are covered.

Our approach has several attractive features. First, the proposed test can detect smooth structural changes and sudden structural breaks with unknown breakdates or unknown number of breaks in regression models with endogeneous regressors. Second, unlike many tests for structural changes in the literature, which often have nonstandard asymptotic distributions, the proposed test is asymptotically pivotal. Third, our test covers both stable and unstable first-stage reduced form models. We need not pretest the stability of the reduced form model. Fourth, no trimming of the boundary region near the end points of the sample period is needed for our test. Fifth, our nonparametric estimation and test are studied in a unified framework. The 2SLL estimators of the time-varying parameters can provide insight into the evolution of the economic relationship.

It is worth noting that two recent papers work on structural changes in linear regression with endogeneity. Based on 2SLS, Hall et al. (2012) develop a methodology for estimation and inference of the parameters of the model allowing for endogenous regressors. Their main focus is the model with a stable reduced form. If the reduced form is not stable, Bai and Perron's (1998) method is first applied to identify break dates. Then the whole sample is divided to subsamples accordingly and their test is applied to every subsample. But when break dates are identified at the beginning or end of the sample or many break dates are identified, their second step procedure may not be implementable. And sample splitting reduces the effective sample size and hence the power of the test. Perron and Yamamoto (2013, 2014) show that under certain assumptions, even in the presence of endogenous regressors, it is still preferable to estimate the break dates and test for structural changes using OLS. But if the main interest is to estimate structural parameters, the 2SLS is still needed.

We emphasize that our 2SLL estimator and the Wald-type test should be viewed as complements, not substitutes of the above-mentioned methods. They are suitable for different scenarios If the structural model has discrete breaks, the 2SLS is more efficient than the 2SLL estimator, which is consistent except for the small neighborhoods near the break points[1]; if the structural model has smooth changes, the 2SLS is inconsistent while the 2SLL is consistent. Moreover, the 2SLS and OLS based tests are suitable for models with a stable reduced form or an unstable reduced form with discrete breaks, while the 2SLL based test is suitable for models with a stable reduced form or an unstable reduced form with smooth structural changes, which would be the main focus of this paper.[2]

In Section 2, we introduce the framework and develop the two stage estimator. Section 3 derives the consistency and asymptotic normality of the estimator. Section 4 states the hypotheses of interest, the form of the test statistic, and its asymptotic null distribution and power properties. In Section 5, a simulation study is conducted to assess the reliability of the asymptotic theory in finite samples and an empirical example is used to illustrate the application of our approach. Section 6 provides concluding remarks. All mathematical proofs are collected in the Appendix. Throughout the paper, C denotes a generic bounded constant.

2. Nonparametric estimation

Consider the model

$$Y_t = X_t^{\tau}\beta(t/T) + \varepsilon_t, \tag{1}$$

where Y_t is a dependent variable, X_t is a $d \times 1$ vector, $\beta(\cdot) : [0, 1] \to \mathbb{R}^d$ is some unknown smooth function, ε_t is an unobservable regression disturbance. We allow some regressors to be correlated with the errors. If X_t is exogenous, Robinson's (1989, 1991), kernel estimation and Cai's (2007) local linear estimation can be

[1] The Wald-type test is consistent although the 2SLL yields inconsistent estimation in the neighborhoods around the jump points.

[2] Abrupt structural breaks are indeed very important and that is part of the reason why the literature on estimating and detecting abrupt structural breaks is huge and still growing. On the other hand, smooth structural changes are also empirically relevant as many leading driving forces of structural changes such as technological progress, preference change and policy switch usually exhibit evolutionary changes in the long term. Therefore, we would like to fill the gap in the literature by focusing on smooth structural changes.