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*Publication date:*  
2011

[Link to publication](#)

*Citation for published version (HARVARD):*

Verardi, V & Debarsy, N 2011, *Robinson's square root of  $n$  consistent semiparametric estimator in Stata.*

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# Robinson's $\sqrt{n}$ -consistent semiparametric regression estimator in Stata

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March 17, 2011

## Abstract

This paper describes Robinson's (1988) double residual semiparametric regression estimator and Hardle and Mammen's (1993) specification test implementation in Stata. Some simple simulations illustrate how this newly coded estimator outperforms the already available semiparametric `plreg` command.

**Keywords:** semipar, Semiparametric estimation

**JEL Classification:** C14, C21

## 1 Introduction

The objective of this paper is to present the implementation in Stata of Robinson's (1988) double residual semiparametric regression estimator. Also, to check if the nonparametric part of the relation may be approximated by

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a polynomial functional form, we introduce Hardle and Mammen's (1993) specification test as an option in the programmed estimator. We also briefly describe this test.

The structure of the paper is the following: in Section 2, Robinson's (1988) semiparametric regression estimator and Hardle and Mammen's (1993) specification test are described. In Section 3, the implemented Stata command (`semipar`) is presented. Some simple simulations assessing the performance of the estimator and of the test are performed in Section 4. In Section 5, we illustrate the use of the `semipar` command with an empirical application. Section 6 concludes.

## 2 Estimation method

### 2.1 Robinson's (1988) semiparametric regression estimator

Consider a general model of the type

$$y_i = \theta_0 + \mathbf{x}_i\theta + f(z_i) + \varepsilon_i, \quad i = 1, \dots, N \quad (1)$$

where  $y_i$  is the value taken by the dependent variable for individual  $i$ ,  $\mathbf{x}_i$  is the row vector of characteristics for individual  $i$ ,  $\theta_0$  is a constant term and  $\varepsilon_i$  is the disturbance assumed to have zero mean and constant variance  $\sigma_\varepsilon^2$ . Variable  $\mathbf{z}$  is an explanatory variable that enters the equation nonlinearly according to a non-binding function  $f$ . This model can be estimated using Robinson's (1988) double residual methodology that starts by applying a conditional expectation to both sides of (1). This leads to

$$E(y_i|z_i) = \theta_0 + E(\mathbf{x}_i|z_i)\theta + f(z_i) \quad i = 1, \dots, N \quad (2)$$

By subtracting (2) from (1), we have

$$y_i - E(y_i|z_i) = (\mathbf{x}_i - E(\mathbf{x}_i|z_i))\theta + \varepsilon_i \quad i = 1, \dots, N \quad (3)$$

If the conditional expectations are known, parameter vector  $\theta$  can easily be estimated by fitting (3) by ordinary least squares. If they are unknown, they have to be estimated by calling on some consistent estimators  $y_i = m_y(z_i) + \varepsilon_{1i}$  and  $x_{ki} = m_{x_k}(z_i) + \varepsilon_{2ki}$ , where  $k = 1, \dots, K$  is the index of the explanatory variables entering the model parametrically. Robinson's (1988) double residual estimator is hence the OLS estimation of model

$$y_i - \hat{m}_y(z_i) = (\mathbf{x}_i - \hat{m}_\mathbf{x}(z_i))\theta + \varepsilon_i \quad i = 1, \dots, N \quad (4)$$

where  $\mathbf{x}_i - \hat{m}_\mathbf{x}(z_i)$  is the row-vector of the differences between each explanatory variable  $x_{ki}$  and the fitted conditional expectation of  $x_{ki}$  given  $z_i$ .

The estimated coefficients vector is therefore

$$\hat{\theta} = \left( \sum_i (\mathbf{x}_i - \hat{m}_{\mathbf{x}}(z_i))' (\mathbf{x}_i - \hat{m}_{\mathbf{x}}(z_i)) \right)^{-1} \sum_i (\mathbf{x}_i - \hat{m}_{\mathbf{x}}(z_i))' (y_i - \hat{m}_y(z_i)) \quad (5)$$

with variance (if errors are i.i.d)

$$Var(\hat{\theta}) = \sigma_\varepsilon^2 \left( \sum_i (\mathbf{x}_i - \hat{m}_x(z_i))' (\mathbf{x}_i - \hat{m}_x(z_i)) \right)^{-1} \quad (6)$$

where  $\sigma_\varepsilon^2$  is the variance of the error term. If errors are non i.i.d., standard sandwich and cluster variance formulas can be used.

Having estimated parameter vector  $\theta$ , it is now possible to fit the nonlinear relation between  $z_i$  and  $y_i$  by simply estimating equation (7) presented below nonparametrically.

$$y_i - \mathbf{x}_i \hat{\theta} = \theta_0 + f(z_i) + \varepsilon_i, \quad i = 1, \dots, N \quad (7)$$

## 2.2 Hardle and Mammen's (1993) test

It is sometimes suggested that nonparametric functions may be approximated by some parametric polynomial alternative. To test for the appropriateness of such an approximation, Hardle and Mammen (1993) propose a statistic which compares the nonparametric and parametric regression fits using squared deviations between them. The test-statistic is:

$$T_n = N\sqrt{h} \sum_{i=1}^N \left( \hat{f}(z_i) - \hat{f}(z_i, \theta) \right)^2 \pi(\cdot) \quad (8)$$

where  $\hat{f}(z_i)$  is the nonparametric function estimated in (7),  $\hat{f}(z_i, \theta)$  is an estimated parametric function and  $h$  is the bandwidth used.  $\pi(\cdot)$  is a weight function. To obtain critical values for the test, Hardle and Mammen (1993) suggest to call on simulated values obtained by wild bootstrap. Obviously, an absence of rejection of the null (i.e. "accepting" the parametric model) means that the polynomial adjustment is at least of the degree that has been tested.

We implemented this estimator in Stata under the command `semipar` which is described below.

## 3 The semipar command

The `semipar` command fits Robinson's double residual estimator in the case of a unique variable entering the model nonparametrically. The default kernel regression used for all stages is a gaussian kernel weighted local polynomial fit. This kernel is of order 2. The optimal bandwidth used minimizes the conditional weighted mean integrated squared error.

The general syntax for the command is:

```
semipar varlist [ if ] [ in ] , nonpar(string) [ generate(string)
  partial(string) nograph ci level(#) title(string) ytitle(string)
  xtitle(string) robust cluster(varname) test(#) nsim(#)
  weight(varname) degree(#) ]
```

The first option, **nonpar**, is compulsory and necessary to declare which variable enters the model nonparametrically. All other choices are optional. The first one, **generate**, reproduces the “nonparametrically” fitted dependent variable. The user chooses the name of this new variable by defining it in parentheses. Similarly, the **partial** option is needed to generate a new variable that contains the parametric residuals (i.e. the left-hand side of equation (7)). The option **nograph** will be used if the user does not want the graph of the nonparametric fit of the variable set in **nonpar** to appear. The **ci** option allows to visualize the confidence interval around the nonparametric fit, while the **level** option sets the level of confidence for inference (by default set to 95%). The options **title**, **ytitle** and **xtitle** are used to indicate respectively the title and the labels of the axes of the graph illustrating the nonparametric relation between the dependent variable and the variable defined in the **nonpar** option. The **robust** and **cluster** options call for standard errors of the estimated parameters that are respectively resistant to heteroskedasticity and clustered errors. The **test** option implements Hardle and Mammen’s (1993) statistic to test whether the nonparametric fit could be approximated by a polynomial fit, the order of which must be set by the user. For the sake of clarity, we rescaled the statistic in such a way that it can be compared with the quantile of a Normal distribution. Note however that the test is not normally distributed. The **nsim** option defines the number of bootstrap replicates used to get inference. Its default value is set to 20. The **weight** option allows to introduce a weighting vector for the test (i.e.  $\pi(\cdot)$  in equation (8)). By default, this weighting vector is set to  $\iota_N/N$  with  $\iota_N$  a unit vector of dimension  $N$ . Finally, the **degree** option allows the user to specify the degree of the local polynomial fit used to nonparametrically estimate the regressions. By default, it is set to 1.

To assess the performance of the programmed estimator, in the next section we present some simple simulations in which we compare this estimator with the already available **plreg** command. The latter implements Yatchew’s (1998) difference estimator where the nonparametric part in (1) is partialled out by differencing rather than by removing the conditional expectations. Since the highest efficiency of Yatchew’s (1998) estimator is attained by a differencing of order 10, we will use this differencing order as a benchmark.

Table 1: Comparison between **semipar** and **plreg**

	Bias $x_2$	Bias $x_3$	MSE $x_2$	MSE $x_3$
<i>plreg</i>	-0.4695	-0.1039	0.2208	0.0111
<i>semipar</i>	-0.0435	-0.0183	0.0022	0.0007

## 4 Simulations

The simulation setup is the following. To begin, we generate (for a sample of 300 observations) two explanatory variables  $x_2$  and  $x_3$  from two independent  $N(0, 1)$ . An additional random variable  $x_1$  is generated from a discrete Uniform distribution on  $[-10, 10]$ . This sample design remains unchanged for all simulations. Then, for each replication, we generate an error term  $e$  from a standard normal and create variable  $y$  according to DGP  $y = x_1 + x_1^2 + x_2 + x_3 + e$ . We run the **semipar** and **plreg** estimators for each replicate and Table 1 reports both the bias and MSE of the coefficients associated with  $x_2$  and  $x_3$ . We carry out 1000 simulations. The variable that enters the equation nonparametrically is generated from a discrete Uniform distribution on purpose to illustrate the fragility of **plreg** with respect to this kind of data. Robinson's (1988) estimator, that is based on partialling out the nonparametric part removing conditional expectations rather than by differencing, behaves much better.

In this setup, Robinson's (1988) estimator leads to smaller biases than Yatchew's (1998) differencing estimator. From equation (7), this also implies that the nonparametric fit is better estimated by **semipar** than by **plreg**.

To illustrate the fitting performance of the proposed estimation procedure, we generate four samples according to the following DGPs:

- a)  $y = x_2 + x_3 + e$
- b)  $y = x_1 + x_2 + x_3 + e$
- c)  $y = x_1 + x_1^2 + x_2 + x_3 + e$
- d)  $y = x_1 - x_1^2 - x_1^3 + x_2 + x_3 + e$ .

In Figure (1), we present the scatter plots, the non-parametric fit (thick plain line) and the true DGP (red dashed line) related to the four DGPs described above. As expected, the results are unambiguous.

In the absence of any relation between  $x_1$  and  $y$  (panel a), no clear pattern emerges and the non-parametric curve lies close to the horizontal line (the true DGP). In the three other cases (panels b, c and d), the nonparametric estimation of the relation matches the true functional form quite well.

As mentioned in the previous section, the  $T_n$  statistic assesses the adequacy of a polynomial adjustment compared to a nonparametric fit. Table

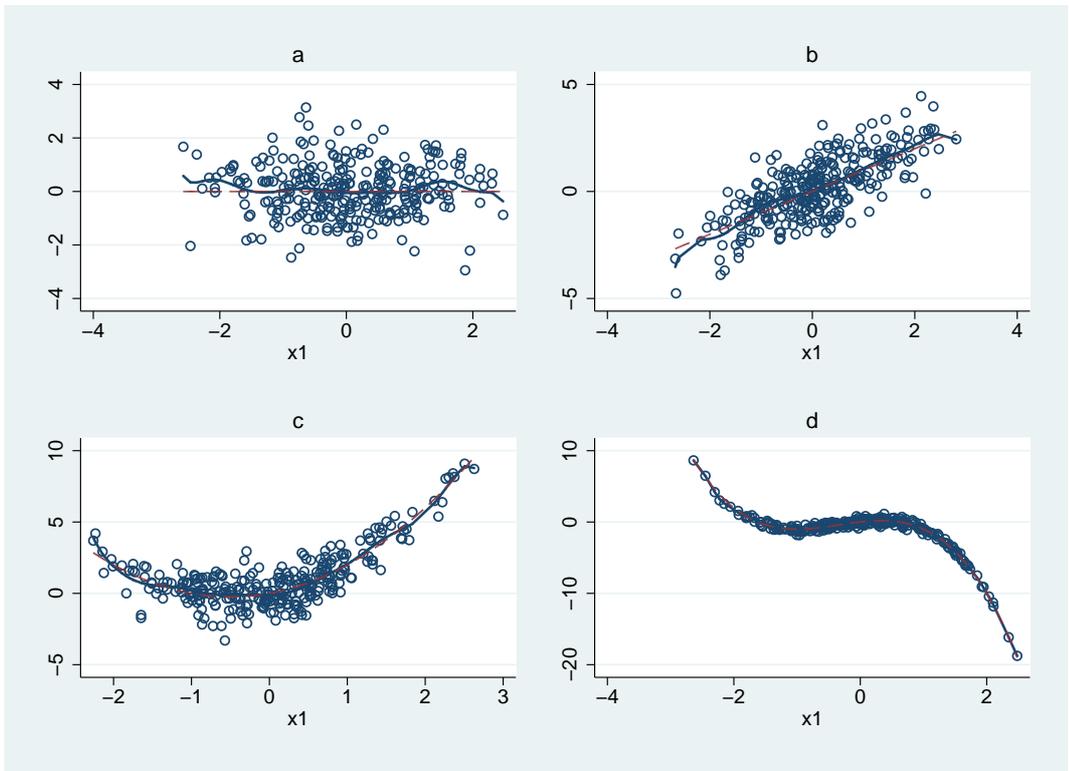


Figure 1: Non-parametric fit of the four DGPs

Table 2: Performance of the comparison Test  $T_n$ 

		Order tested			
		0	1	2	3
	0	0.053	0.06	0.055	0.039
True	1	1	0.064	0.055	0.021
Order	2	1	1	0.06	0.062
	3	1	1	1	0.066

Figures correspond to rejection rates of the test.

2 presents the performance of the test for the DGPs described above. The rows indicate the order of the generated polynomial while the columns specify the order of the polynomial that has been tested. Thus, the diagonal (and the upper triangle) elements are the simulated sizes of the test while elements below the main diagonal are some measure of power. To construct this table we replicated the DGPs 1000 times. Each time a new error term is randomly drawn and a new dependent variable is generated (the design space remains unchanged). Inference for the test is based on 100 bootstrap replications. We observe that the test has good rejection rates when the order of the polynomial adjustment tested is lower than the generated one. Besides, the size of the test (whose theoretical value is set at 5%), is very close to its nominal value.

## 5 Example

To illustrate the usefulness of this semiparametric model in empirical applications, we call on a dataset used by Wooldridge (2002) that studies the effects of an incinerator location on housing prices. The data are for houses that were sold during the year 1981 in North Andover, MA; 1981 was the year construction began on a local garbage incinerator. The dependent variable is the log of price of houses ( $lprice$ ) and the variable of interest is the distance from the house to the incinerator measured in feet and expressed in logs ( $ldist$ ). To control for confounding effects, the author suggest to include the log of interstate distance ( $linst$ ), the log of the square footage of the house ( $larea$ ), the log of the lot size in square feet ( $lland$ ), the number of rooms ( $rooms$ ), the number of bathrooms ( $baths$ ), and the age of the house ( $age$ ) as additional covariate. However, he also asserts that the effect of the log of the interstate distance is not linear and proposes to consider it squared. In this application we carry out this exercise again but do not impose any functional form to the log of interstate distance and estimate the model semiparametrically. We then check if the square approximation is appropriate. More precisely, we run the following command lines:

```

. use http://fmwww.bc.edu/ec-p/data/wooldridge/HPRICE3
. semipar lprice ldist larea lland rooms baths age, nonpar(linst) xtitle(linst) ci

```

Number of obs = 321  
 R-squared = 0.4437  
 Adj R-squared = 0.4331  
 Root MSE = 0.2646

lprice	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]
ldist	.1083941	.0640184	1.69	0.091	-.0175636 .2343519
larea	.4887243	.0668208	7.31	0.000	.3572527 .6201959
lland	.0866459	.036037	2.40	0.017	.0157423 .1575495
rooms	.0436451	.0221781	1.97	0.050	9.12e-06 .087281
baths	.0806555	.0335251	2.41	0.017	.014694 .146617
age	-.003481	.0005436	-6.40	0.000	-.0045506 -.0024114

The results of the parametric part (see Stata output above) show that the distance from the incinerator does not seem to be significant (the t-stat associated with the coefficient is smaller than the critical value of 1.96).

As far as the effect of the log of the interstate distance is concerned, Figure (2) shows that it is clearly nonlinear.

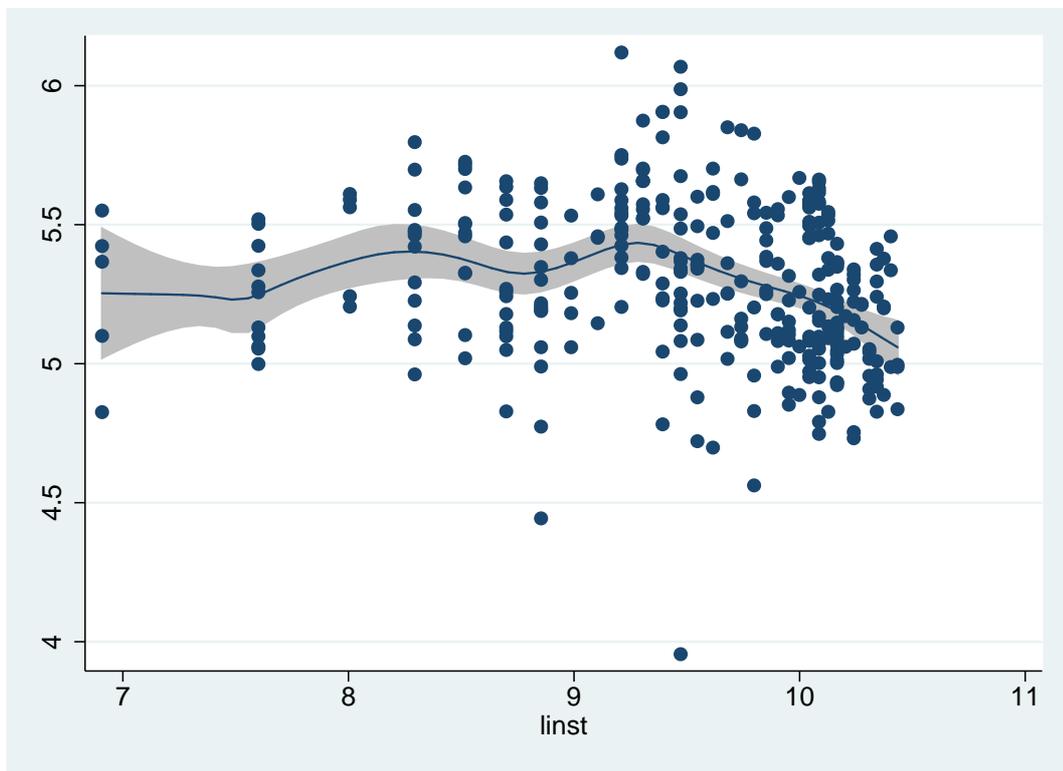


Figure 2: Nonlinear link between the price and interstate distance (in logs)



shown.

## 7 Acknowledgments

We would like to thank all our colleagues at CRED, ECARES, and CERPE as well as Emmanuel Flachaire, Marjorie Gassner, Whitney Newey, Christopher Parmeter and Sébastien Van Belleghem. Vincenzo Verardi is an associated researcher of the National Science Foundation of Belgium and gratefully acknowledges their financial support. Nicolas Debarsy is a research fellow of the National Science Foundation of Belgium and gratefully acknowledges their financial support.

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