

# The HIP package

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## Abstract

The HIP package is a collection of `gretl` scripts to estimate probit models which may feature endogenous regressors and/or heteroskedasticity. Estimation is done via maximum likelihood under the assumption of multivariate normality.

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## 1 Introduction

The HIP package is a collection of `gretl` scripts to estimate probit models which may feature endogenous regressors and/or heteroskedasticity. Estimation is done via maximum likelihood under the assumption of multivariate normality.

Most other packages provide similar facilities separately. However, the additional computational complexity of handling, at the same time, endogeneity and the special form of conditional heteroskedasticity we deal with here is minimal, so we give a command which naturally nests the two special cases but can just as easily handle the general one.

## 2 The model

The model which HIP handles can be thought of as the union of the familiar IV-probit model and the heteroskedastic probit model, that is models that can be written in the following form:

$$y_i^* = \mathbf{Y}_i' \boldsymbol{\beta}_1 + \mathbf{X}_{1i}' \boldsymbol{\beta}_2 + \varepsilon_i = \mathbf{Z}_i' \boldsymbol{\beta} + \varepsilon_i \quad (1)$$

$$\mathbf{Y}_i = \boldsymbol{\Pi}_1' \mathbf{X}_{1i} + \boldsymbol{\Pi}_2' \mathbf{X}_{2i} + \mathbf{u}_i = \boldsymbol{\Pi}' \mathbf{X}_i + \mathbf{u}_i \quad (2)$$

$$\left( \begin{array}{c} \varepsilon_i \\ \mathbf{u}_i \end{array} \middle| \mathbf{X}_i, \mathbf{W}_i \right) \sim N \left[ \begin{pmatrix} 0 \\ \mathbf{0} \end{pmatrix}, \begin{pmatrix} \sigma_i^2 & \sigma_i \boldsymbol{\lambda}' \\ \sigma_i \boldsymbol{\lambda} & \boldsymbol{\Sigma} \end{pmatrix} \right] \quad (3)$$

$$\sigma_i = \exp \{ \mathbf{W}_i' \boldsymbol{\alpha} \} \quad (4)$$

The variable  $y_i^*$  is assumed to be unobservable; what is observable is  $y_i = I(y_i^* > 0)$ , where  $I()$  is the indicator function.  $\mathbf{Y}_i$  is a vector of  $p$  endogenous continuous variables and  $\mathbf{X}_{1i}$  is a  $k_1$ -vector of exogenous variables; equation (2) is the reduced form for the endogenous regressors in (1), and also includes a  $k_2$ -vector of instruments  $\mathbf{X}_{2i}$ .

The notable feature of equation (3) (apart from the customary normality assumption) is the fact that  $\varepsilon_i$  is allowed to be conditionally heteroskedastic, with variance given by equation (4), where  $\mathbf{W}_i$  is a vector of  $q$  exogenous variables. Of course, the elements of  $\mathbf{W}_i$  may also be elements of  $\mathbf{X}_i$ . For identification purposes, though,  $\mathbf{W}_i$  should not include a constant term or equivalent variables, such as for example a complete set of dummies.

Note that the familiar IV-probit model arises as a special case of the above under the constraint  $\boldsymbol{\alpha} = \mathbf{0}$  whereas, in a parallel fashion, the so-called “heteroskedastic probit model” corresponds to the above model under the constraint  $\boldsymbol{\lambda} = \mathbf{0}$ , in which case obviously the parameters in the two equations (1) and (2) become independent and can be estimated separately.

## 3 A few examples

### 3.1 IV probit — through a script

To begin with, we’ll apply IV probit to a time-honoured problem, that is female labour force participation.<sup>1</sup> We’ll use the immortal dataset used in Mroz (1987), supplied among **gretl**’s example datasets. We will exemplify HIP through a script first, and then we’ll take a look at the GUI hook that HIP provides. Of course, in both examples we’ll assume HIP has correctly been installed.

The script can be very simple:

```
include HIP.gfn
open mroz87.gdt --quiet

list X1 = const WE KL6
series other_inc = (FAMINC - WW*WHR5) / 1000
HIP(LFP, X1, other_inc, HE)
```

---

<sup>1</sup>Examples like the one presented here are quite common in several other software packages. Go check.

which yields:

```

Probit model with endogenous regressors
ML, using observations 1-753
Dependent Variable: LFP
Instrumented: other_inc
Instruments: const, WE, KL6, HE
Parameter covariance matrix: OPG

```

|           | coefficient | std. error | z      | p-value  |     |
|-----------|-------------|------------|--------|----------|-----|
| const     | -1.20677    | 0.277614   | -4.347 | 1.38e-05 | *** |
| WE        | 0.179911    | 0.0297031  | 6.057  | 1.39e-09 | *** |
| KL6       | -0.646468   | 0.102047   | -6.335 | 2.37e-10 | *** |
| other_inc | -0.0332341  | 0.0156644  | -2.122 | 0.0339   | **  |

```

Log-likelihood      -3325.8255  Akaike criterion      6671.6509
Schwarz criterion   6717.8916  Hannan-Quinn        6689.4651
Conditional ll      -465.248010  Cragg-Donald stat.   51.707

```

Overall test (Wald) = 73.9702 (3 df, p-value = 0.0000)  
Endogeneity test (Wald) = 0.446846 (1 df, p-value = 0.5038)

In this case we used the function `HIP`, which takes as arguments

1. the dependent variable
2. the exogenous explanatory variables (normally as a list)
3. the endogenous explanatory variables (a list or, as in this this case, a single variable name)
4. the instruments (a list or, as in this this case, a single variable name)

The function `HIP` in fact accepts more arguments than this, but we'll leave that for later. It should also be said that the function `HIP` produces a `gretl` bundle as output, although in this example the function is called in such a way that the bundle is discarded. To store the estimated model in a bundle called "Bonham", you would call the `HIP` function like this:

```
Bonham = HIP(LFP, X1, other_inc, HE)
```

The estimate you get for standard errors uses OPG (Outer Product of Gradients) as the standard method for computing the covariance matrix of the estimates. This choice was made for the sake of performance but, as will be shown below, other methods are readily available.

The auxiliary statistics reported by `HIP` are the usual likelihood-based criteria (besides the total likelihood, the maximized value for its conditional component only is also reported—see section A.1 in the appendix for details) and the Cragg–Donald statistic as a way to check for weak instruments. The endogeneity test is a test for  $\lambda = 0$ , the overall test is a test for  $\beta = 0$  (apart from the intercept).

## 3.2 IV probit — through the GUI

After installing `HIP` by going to *Help > Check for addons*, you'll find it among the other function packages installed on your box (*Tools > Function packages > On local machine*). Double-click and edit the window that appears like in Figure 1.



Figure 1: HIP GUI hook

| IV/Heteroskedastic  |             |                    |           |              |
|---|-------------|--------------------|-----------|--------------|
| Probit model with endogenous regressors                     |             |                    |           |              |
| ML, using observations 1-753                                |             |                    |           |              |
| Dependent Variable: LFP                                     |             |                    |           |              |
| Instrumented: other_inc                                     |             |                    |           |              |
| Instruments: const, WE, KL6, HE                             |             |                    |           |              |
| Parameter covariance matrix: Hessian                        |             |                    |           |              |
|   | coefficient | std. error         | z         | p-value      |
| const   | -1.20677    | 0.280118           | -4.308    | 1.65e-05 *** |
| WE  | 0.179911    | 0.0299560          | 6.006     | 1.90e-09 *** |
| KL6   | -0.646468   | 0.100720           | -6.418    | 1.38e-10 *** |
| other_inc   | -0.0332341  | 0.0160563          | -2.070    | 0.0385 **    |
| "First-stage" regressions                                   |             |                    |           |              |
|   | coefficient | std. error         | z         | p-value      |
| const   | -0.305076   | 2.20097            | -0.1386   | 0.8898       |
| WE  | 0.457795    | 0.218603           | 2.094     | 0.0362 **    |
| KL6   | -0.285786   | 0.759224           | -0.3764   | 0.7066       |
| HE  | 1.19099     | 0.165518           | 7.196     | 6.22e-13 *** |
| Log-likelihood  | -3325.8255  | Akaike criterion   | 6671.6509 |              |
| Schwarz criterion   | 6717.8916   | Hannan-Quinn       | 6689.4651 |              |
| Conditional ll  | -465.248010 | Cragg-Donald stat. | 51.707    |              |
| Overall test (Wald) = 76.2668 (3 df, p-value = 0.0000)      |             |                    |           |              |
| Endogeneity test (Wald) = 0.418081 (1 df, p-value = 0.5179) |             |                    |           |              |

Figure 2: HIP output



Figure 3: Icon view with a HIP bundle

Note that in this case we changed the default value of “Verbosity” from 1 to 2 and the default value of “Covariance matrix estimation” from “OPG” to “Hessian”. This will have the effect of showing us the first stage equation as well, and of using the Hessian instead of the OPG as the method for computing standard errors. All this is apparent in Figure 2.

By using the *Save* menu, you can choose the individual elements of the bundle to store away for later use if you want. Alternatively, you can save the bundle as a model via the *File > Save to session as icon* menu entry. If you do, assuming that you called your bundle “Bonham” again, then it will show in the “Icon view” gretl window, together with other session elements you want to keep (see Figure 3).

### 3.3 Heteroskedastic probit

Here, we’ll replicate the example given in William Greene’s textbook (7th edition), which also uses Mroz’s dataset. The script goes like this:

```
include HIP.gfn

open mroz87.gdt --quiet
series WA2 = WA^2
series KIDS = (KL6 + K618)>0
income = FAMINC /10000

list X = const WA WA2 income KIDS WE
list Z = income KIDS

Mitchell = HIP_setup(LFP, X, null, null, Z)
HIP_setoption(&Mitchell, "vcvmeth", 1)

set stopwatch
HIP_estimate(&Mitchell)
printf "Elapsed time = %g seconds\n", $stopwatch

HIP_printout(&Mitchell)
```

Note that in this case we did not use the HIP function, but instead we split its workload between four separate functions:

**HIP\_setup** Sets up the model: basically, it has the same parameters as the all-rounder HIP function seen above. Returns a bundle.

**HIP\_setoption** Set some details of the estimation procedure; in this case, we used it to compute standard errors using the inverse Hessian instead of the OPG matrix, so as to match exactly the figures reported in Greene’s book.

**HIP\_estimate** Estimates the model: takes as argument the bundle address, plus an optional scalar for the verbosity.

**HIP\_printout** Prints out the results contained in the bundle.

This division of tasks may be convenient at times, because it gives you finer control over “what happens if”. For example, the Cragg–Donald statistic gets computed during the initialization of the bundle and you may wish to decide whether to proceed with estimation or not depending on how strong your instruments are.

The output, replicating table 17.7 in Greene’s textbook, should look like this:

```
Heteroskedastic probit model
ML, using observations 1-753
Dependent Variable: LFP
Parameter covariance matrix: Hessian
```

|        | coefficient | std. error | z      | p-value |     |
|--------|-------------|------------|--------|---------|-----|
| const  | -6.02985    | 2.49810    | -2.414 | 0.0158  | **  |
| WA     | 0.264291    | 0.118159   | 2.237  | 0.0253  | **  |
| WA2    | -0.00362838 | 0.00143387 | -2.530 | 0.0114  | **  |
| income | 0.424441    | 0.221839   | 1.913  | 0.0557  | *   |
| KIDS   | -0.879093   | 0.302753   | -2.904 | 0.0037  | *** |
| WE     | 0.140149    | 0.0518536  | 2.703  | 0.0069  | *** |

Variance

|        | coefficient | std. error | z       | p-value   |
|--------|-------------|------------|---------|-----------|
| KIDS   | -0.140752   | 0.323745   | -0.4348 | 0.6637    |
| income | 0.312918    | 0.122810   | 2.548   | 0.0108 ** |

```
Log-likelihood      -487.6356 Akaike criterion      991.2712
Schwarz criterion   1028.2637 Hannan-Quinn        1005.5225
```

```
Overall test (Wald) = 14.5557 (5 df, p-value = 0.0124)
Heteroskedasticity test (LR) = 6.42453 (2 df, p-value = 0.0403)
Chesher and Irish normality test = 6.23055 (2 df, p-value = 0.0444)
```

### 3.4 Let’s get HIP: heteroskedasticity and endogeneity at the same time

The script goes:

```
set verbose off
include HIP.gfn

open mroz87.gdt -q
```

```
list EXOG = const WA CIT K618
list ENDOG = WE
list ADDIN = WMED WFED
list HETVAR = HW
```

```
Paice = HIP(LFP, EXOG, ENDOG, ADDIN, HETVAR, 2)
```

In this case, the “2” tells HIP to be moderately verbose: don’t print out all the iterations, but show us the “first stage” coefficients. The output is as follows:

```
Heteroskedastic probit model with endogenous regressors
ML, using observations 1-753
Dependent Variable: LFP
Instrumented: WE
Instruments: const, WA, CIT, K618, WMED, WFED
Parameter covariance matrix: OPG
```

|       | coefficient | std. error | z       | p-value   |
|-------|-------------|------------|---------|-----------|
| const | -0.551804   | 1.36344    | -0.4047 | 0.6857    |
| WA    | -0.0304390  | 0.0172559  | -1.764  | 0.0777 *  |
| CIT   | -0.0242784  | 0.208991   | -0.1162 | 0.9075    |
| K618  | -0.0927252  | 0.0896549  | -1.034  | 0.3010    |
| WE    | 0.199646    | 0.101330   | 1.970   | 0.0488 ** |

Variance

|    | coefficient | std. error | z     | p-value   |
|----|-------------|------------|-------|-----------|
| HW | 0.117934    | 0.0571806  | 2.062 | 0.0392 ** |

"First-stage" regressions

|       | coefficient | std. error | z      | p-value      |
|-------|-------------|------------|--------|--------------|
| const | 9.68554     | 0.586171   | 16.52  | 2.49e-61 *** |
| WA    | -0.0159435  | 0.0104384  | -1.527 | 0.1267       |
| CIT   | 0.495907    | 0.152627   | 3.249  | 0.0012 ***   |
| K618  | -0.136765   | 0.0612498  | -2.233 | 0.0256 **    |
| WMED  | 0.180089    | 0.0265972  | 6.771  | 1.28e-11 *** |
| WFED  | 0.168085    | 0.0253072  | 6.642  | 3.10e-11 *** |

```
Log-likelihood      -2069.9119 Akaike criterion      4167.8239
Schwarz criterion   4232.5608 Hannan-Quinn        4192.7637
Conditional ll      -494.848818 Cragg-Donald stat.  103.337
```

```
Overall test (Wald) = 6.36207 (4 df, p-value = 0.1737)
Endogeneity test (Wald) = 0.509859 (1 df, p-value = 0.4752)
Test for overidentifying restrictions (LM) = 9.15786 (1 df, p-value = 0.0025)
Heteroskedasticity test (Wald) = 4.25379 (1 df, p-value = 0.0392)
```

## 4 Computational details

HIP uses the analytical score and BFGS as the preferred optimization method. The analytical Hessian is not implemented yet, but may be in the future.

Like other estimators that depend on numerical methods, HIP can sometimes run into numerical problems, leading to non-convergence. If this happens, here are some points to consider.

- Checking exactly what happens during maximization can be very informative; try setting the verbosity parameter to 3.
- Scaling of the data (especially  $\mathbf{Y}_i$ ) can be an issue; we do our best, but hey, give us a hand (for example, multiply or divide by 1000 depending of the original scale of the data).
- Weak instruments: in some cases, there's little that can be done; see for example the artificially-generated dataset contained in the `MonteCarlo.inp` example script, contained in the examples directory. We do some heuristics, but we're not omnipotent.

## 5 Changelog

**1.1** Guard against the inclusion of a constant in the `HETVAR` list. Fix a typo in an error message. Modernise internal syntax in a few places.

**1.0** Initial release

## References

- Chesher, A. and M. Irish (1987) 'Residual analysis in the grouped and censored normal linear model', *Journal of Econometrics* 34: 33–61.
- Cragg, J. G. and S. G. Donald (1993) 'Testing identifiability and specification in instrumental variable models', *Econometric Theory* 9: 222–240.
- Mroz, T. (1987) 'The sensitivity of an empirical model of married women's hours of work to economic and statistical assumptions', *Econometrica* 5: 765–799. URL <https://doi.org/10.2307/1911029>.
- Rivers, D. and Q. H. Vuong (1988) 'Limited information estimators and exogeneity tests for simultaneous probit models', *Journal of Econometrics* 39(3): 347–366.



## A The boring stuff

For computational purposes, we reparametrize the model using the Cholesky decomposition  $\Sigma^{-1} = CC'$ . Moreover, by defining the quantities below it is possible to reparametrize the joint density in a computationally convenient way:

$$\begin{aligned}\nu_i &= \frac{1}{\sqrt{1 - \psi'\psi}} \left( \frac{\mathbf{Z}'_i \boldsymbol{\beta}}{\sigma_i} + \boldsymbol{\omega}'_i \psi \right) \\ \psi &= C' \boldsymbol{\lambda} \\ \boldsymbol{\omega}_i &= C' (\mathbf{Y}_i - \Pi \mathbf{X}_i) \\ \boldsymbol{\pi} &= \text{vec}(\Pi) \\ \mathbf{c} &= \text{vech}(C)\end{aligned}$$

The estimable parameters are  $\theta' = [\boldsymbol{\beta}', \boldsymbol{\alpha}', \boldsymbol{\pi}', \psi', \mathbf{c}']$

### A.1 The loglikelihood

As usual in such models, we divide the loglikelihood for each observation into a marginal and a conditional component:

$$\begin{aligned}\ell_i &= \ell_i^m + \ell_i^c \\ \ell_i^c &= \ln P(y_i | \mathbf{X}_i, \mathbf{W}_i, \mathbf{u}_i) \\ \ell_i^m &= \ln f(\mathbf{u}_i | \mathbf{X}_i, \mathbf{W}_i)\end{aligned}$$

The marginal component is nothing but an ordinary Gaussian loglikelihood:

$$\ell_i^m = -\frac{p}{2} \ln(2\pi) + \sum_{j=1}^p \ln c_{jj} - \frac{1}{2} \boldsymbol{\omega}'_i \boldsymbol{\omega}_i$$

The conditional component is itself rather simple:

$$\ell_i^c = y_i \ln \Phi(\nu_i) + (1 - y_i) \ln [1 - \Phi(\nu_i)] \quad (5)$$

The only feature that sets  $\ell_i^c$  apart from an ordinary probit loglikelihood is that the index function depends non-linearly on some of the parameters of the model, unless  $\boldsymbol{\alpha}$  and  $\psi$  are both zero.

### A.2 The score

The analytical score will be derived in steps: first the marginal component, then the conditional component. Of course, the chain rule will be very useful.

Note first that the marginal component only depends on  $\boldsymbol{\pi}$  (through  $\boldsymbol{\omega}_i$ ) and  $\mathbf{c}$ . Hence,

$$\frac{\partial \ell_i^m}{\partial \boldsymbol{\pi}} = \frac{\partial \ell_i^m}{\partial \boldsymbol{\omega}_i} \frac{\partial \boldsymbol{\omega}_i}{\partial \boldsymbol{\pi}} = \boldsymbol{\omega}'_i (\mathbf{X}'_i \otimes C') = \mathbf{X}'_i \otimes (C \boldsymbol{\omega}_i)'$$

and

$$\frac{\partial \ell_i^m}{\partial \mathbf{c}} = \tilde{\mathbf{c}}' - \boldsymbol{\omega}'_i \frac{\partial \boldsymbol{\omega}_i}{\partial \mathbf{c}} = \tilde{\mathbf{c}}' - [\boldsymbol{\omega}'_i \otimes (\mathbf{Y}_i - \Pi \mathbf{X}_i)'] S$$

where  $\tilde{\mathbf{c}}$  is defined as  $\text{vech}[(I \odot C)^{-1}]$  and  $S$  is a selection matrix  $S = \frac{\partial \text{vec}(C)}{\partial \text{vech}(C)}$ .

For the purpose of computing the score for the conditional component, note that  $\ell_i^c$  depends on the parameters only through the index function  $\nu_i$ , so  $\frac{\partial \ell_i^c}{\partial \theta}$  can be evaluated as

$$\frac{\partial \ell_i^c}{\partial \theta} = \frac{\partial \ell_i^c}{\partial \nu_i} \frac{\partial \nu_i}{\partial \theta},$$

define  $\mu(\nu_i)$  as

$$\mu(\nu_i) = \frac{\partial \ell_i^c}{\partial \nu_i} = y_i \frac{\phi(\nu_i)}{\Phi(\nu_i)} - (1 - y_i) \frac{\phi(\nu_i)}{1 - \Phi(\nu_i)}$$

which is the customary (signed) inverse Mills ratio. Then,

$$\begin{aligned} \frac{\partial \nu_i}{\partial \beta} &= \frac{1}{\sigma_i \sqrt{1 - \psi' \psi}} \mathbf{Z}'_i \\ \frac{\partial \nu_i}{\partial \alpha} &= \frac{\partial \nu_i}{\partial \sigma_i} \frac{\partial \sigma_i}{\partial \alpha} = \left[ -\frac{\mathbf{Z}'_i \beta}{\sigma_i^2 \sqrt{1 - \psi' \psi}} \right] \sigma_i \mathbf{W}'_i = - \left( \frac{\mathbf{Z}'_i \beta}{\sigma_i \sqrt{1 - \psi' \psi}} \right) \mathbf{W}'_i \\ \frac{\partial \nu_i}{\partial \psi} &= \frac{1}{\sigma_i^2 (1 - \psi' \psi)} \left[ \sigma_i^2 \sqrt{1 - \psi' \psi} \omega'_i - \frac{\sigma_i^2}{2} \nu_i (-2 \cdot \psi') \right] = \frac{\omega'_i}{\sqrt{1 - \psi' \psi}} + \frac{\nu_i \psi'}{1 - \psi' \psi} \\ \frac{\partial \nu_i}{\partial \mathbf{c}} &= \frac{\psi'}{\sqrt{1 - \psi' \psi}} \frac{\partial \omega_i}{\partial \mathbf{c}} \\ \frac{\partial \nu_i}{\partial \boldsymbol{\pi}} &= \frac{\psi'}{\sqrt{1 - \psi' \psi}} \frac{\partial \omega_i}{\partial \boldsymbol{\pi}} = -\frac{\psi'}{\sqrt{1 - \psi' \psi}} (\mathbf{X}'_i \otimes C') = \frac{1}{\sqrt{1 - \psi' \psi}} [\mathbf{X}'_i \otimes (C\psi)'] \end{aligned}$$

As a consequence, the score with respect to  $\mathbf{c}$  and  $\boldsymbol{\pi}$  may be written as

$$\begin{aligned} \frac{\partial \ell_i}{\partial \mathbf{c}} &= \frac{\partial \ell_i^m}{\partial \mathbf{c}} + \frac{\partial \ell_i^c}{\partial \mathbf{c}} = \tilde{\mathbf{c}}' + \left( \frac{\psi'}{\sqrt{1 - \psi' \psi}} - \omega'_i \right) \frac{\partial \omega_i}{\partial \mathbf{c}} = \\ &= \tilde{\mathbf{c}}' + \left( \frac{\psi'}{\sqrt{1 - \psi' \psi}} - \omega'_i \right) [I \otimes (\mathbf{Y}_i - \boldsymbol{\Pi} \mathbf{X}_i)'] = \\ &= \tilde{\mathbf{c}}' + \left[ \left( \frac{\psi'}{\sqrt{1 - \psi' \psi}} - \omega'_i \right) \otimes (\mathbf{Y}_i - \boldsymbol{\Pi} \mathbf{X}_i)' \right] \end{aligned}$$

## B List of functions

### B.1 Model setup

---

```
HIP_setoption(bundle *b, string opt, scalar value)
```

---

**Return type :** scalar

**b :** pointer to a bundle containing the model to be estimated, as created by `HIP_setup`;

**opt :** string, the option to set;

**value :** scalar, the option value

This function sets up an option for estimation of the model, so it is typically used after `HIP_setup` and before `HIP_estimate`. At present, the possible values for the `opt` field are “verbose” (possible values: 0 to 3) and “vcvmeth” (possible values: 0 to 2).

For “verbose”, the meaning is: 0 = operate silently, 1 = standard output (default choice), 2 = print the first stage too for IV estimation and 3 = print out ML iterations. For “vcvmeth”, the meaning is: 0 = OPG (default), 1 = Hessian, 2 = Sandwich-robust.

---

```
HIP_setup(series y, list EXOG, list ENDOG[null], list ADDIN[null],
           list HETVAR[null])
```

---

**Return type :** bundle

`y` : a series containing  $y_i$ , the dependent binary variable; **(required)**

`EXOG` : a list containing the exogenous variables  $\mathbf{X}_{1i}$  in  $\mathbf{X}_i$  in equation (1); **(required)**

`ENDOG` : a list containing the exogenous variables  $\mathbf{Y}_i$  in equations (1)–(2)

`ADDIN` a list containing the additional instruments  $\mathbf{X}_{2i}$  in  $\mathbf{X}_i$  in equation (2)

`HETVAR` a list containing the variables  $\mathbf{W}_i$  of the skedastic function in equation (1)

This function sets the model up so that it can be subsequently estimated via `HIP_estimate`.

## B.2 Estimation

---

```
HIP_estimate(bundle *b)
```

---

**Return type :** scalar

`b` : a model bundle in pointer form, as created by `HIP_setup`.

General estimation function. It fills the bundle with the estimated coefficients and many other quantities of interest.

## B.3 Output

---

```
HIP_printout(bundle *b)
```

---

**Return type :** none.

`b` : a model bundle in pointer form, as created by `HIP_setup` and filled up by `HIP_estimate`.

Prints out a model. Note: this function assumes that the bundle it refers to contains a model that has already been estimated. No checks are performed.

## B.4 GUI wrapper

---

```
function bundle HIP(series y, list EXOG, list ENDOG[null], list ADDIN[null], list  
HETVAR[null], int v[0:3:1], int s[0:2:0])
```

---

Using the same argument descriptions as `HIP_setup`, after checking the rank condition (if estimating instrumental variables probit), it calls:

1. `HIP_setup`
2. `HIP_setoption`
3. `HIP_estimate`
4. `HIP_printout`

The parameter `v` controls the verbosity level: 0 = quiet, 1 = main equation only, 2 = first stages, 3 = mle verbose.

## C Bundle elements

| Name                  | Type   | Purpose   |
|-----------------------|--------|---|
| Model descriptors     |        |   |
| n                     | scalar | number of observations  |
| het                   | scalar | acting as a Boolean switch, Heteroskedastic probit  |
| iv                    | scalar | acting as a Boolean switch, Instrumental Variables probit   |
| T                     | scalar | number of observations used   |
| t1                    | scalar | first observation used  |
| t2                    | scalar | last observation used   |
| Data                  |        |   |
| depvar                | series | dependent variable  |
| mEXOG                 | matrix | exogenous regressors  |
| mk1                   | matrix | number of exogenous regressors  |
| mENDOg                | matrix | endogenous regressors   |
| mp                    | matrix | number of endogenous regressors   |
| mADDIN                | matrix | additional instruments  |
| mk2                   | matrix | number of additional instruments  |
| mHETVAR               | matrix | variance regressors   |
| mq                    | matrix | number of variance regressors   |
| mZ                    | matrix | total regressors  |
| mh                    | matrix | number of total regressors  |
| mX                    | matrix | total instruments   |
| mk                    | matrix | number of total instruments   |
| Strings               |        |   |
| depvarname            | string | dependent variable name   |
| mEXOGnames            | string | exogenous regressors names  |
| mENDOgnames           | string | endogenous regressors names   |
| mADDINnames           | string | additional instruments names  |
| mHETVARnames          | string | variance regressors names   |
| mZnames               | string | total regressors names  |
| mXnames               | string | total instruments names   |
| Estimation parameters |        |   |
| vcvtype               | scalar | acting as an integer, method for estimating the covariance matrix: 0 = OPG (default), 1 = empirical Hessian, 2 = Sandwich |

| Estimation results       |        |   |
|--------------------------|--------|---|
| <b>errcode</b>           | scalar | error code from <b>catch</b>  |
| <b>uhat</b>              | series | first stage residuals (Rivers and Vuong, 1988)                                    |
| <b>rescale</b>           | matrix | square root of the diagonal elements of first stage residuals covariance matrix   |
| <b>lnl0</b>              | scalar | second stage log-likelihood (Rivers and Vuong, 1988)                              |
| <b>theta</b>             | matrix | coefficients  |
| <b>VCVtheta</b>          | matrix | covariance matrix   |
| <b>lnl1</b>              | scalar | log-likelihood  |
| <b>lnl1m</b>             | scalar | marginal log-likelihood (if <b>iv</b> )   |
| <b>lnl1c</b>             | scalar | conditional log-likelihood (if <b>iv</b> )  |
| <b>llt</b>               | series | log-likelihood  |
| <b>SCORE</b>             | matrix | score matrix by observation   |
| <b>infocrit</b>          | matrix | information criteria  |
| Diagnostics <sup>2</sup> |        |   |
| <b>WaldAll</b>           | matrix | Wald overall test   |
| <b>WaldEnd</b>           | matrix | Wald endogeneity test   |
| <b>LMOverid</b>          | matrix | LM test for overidentifying restrictions  |
| <b>HETtest</b>           | matrix | if <b>iv</b> Wald test, else LR test of Heteroskedasticity                        |
| <b>CraggDonald</b>       | scalar | Cragg and Donald (1993) statistic for weak instruments                            |
| <b>normtest</b>          | matrix | Conditional moment test for normality of $\varepsilon_i$ Chesher and Irish (1987) |