

# 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.

## Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
<b>2</b>	<b>The model</b>	<b>2</b>
<b>3</b>	<b>A few examples</b>	<b>2</b>
3.1	IV probit — through a script . . . . .	2
3.2	IV probit — through the GUI . . . . .	3
3.3	Heteroskedastic probit . . . . .	4
3.4	Let's get HIP. Heteroskedasticity and endogeneity at the same time. . . . .	5
<b>4</b>	<b>Computational details</b>	<b>7</b>
<b>A</b>	<b>The boring stuff</b>	<b>8</b>
A.1	The loglikelihood . . . . .	8
A.2	The score . . . . .	8
<b>B</b>	<b>List of functions</b>	<b>9</b>
B.1	Model setup . . . . .	9
B.2	Estimation . . . . .	10
B.3	Output . . . . .	10
B.4	GUI wrapper . . . . .	10
<b>C</b>	<b>Bundle elements</b>	<b>11</b>

## 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:

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

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

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

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

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*WHRS) / 1000
HIP(LFP, X1, other_inc, HE)
```

which yields:

---

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

```

Probit model with endogenous regressors
ML, using observations 1-500
Dependent Variable: y
Instrumented: other_inc
Instruments: const, fem_educ, kids, male_educ
Parameter covariance matrix: OPG

```

	coefficient	std. error	z	p-value
const	0.367208	0.460541	0.7973	0.4253
fem_educ	0.211111	0.0290285	7.273	3.53e-13 ***
kids	-0.182093	0.0484024	-3.762	0.0002 ***
other_inc	-0.0542756	0.00608741	-8.916	4.83e-19 ***

Log-likelihood	-2368.2062	Akaike criterion	4756.4124
Schwarz criterion	4798.5585	Hannan-Quinn	4772.9505
Conditional ll	-252.045293	Cragg-Donald stat.	101.060

```

Overall test (Wald) = 154.702 (3 df, p-value = 0.0000)
Endogeneity test (Wald) = 6.84499 (1 df, p-value = 0.0089)

```

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.

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 0 to 1. This will have the effect of showing us

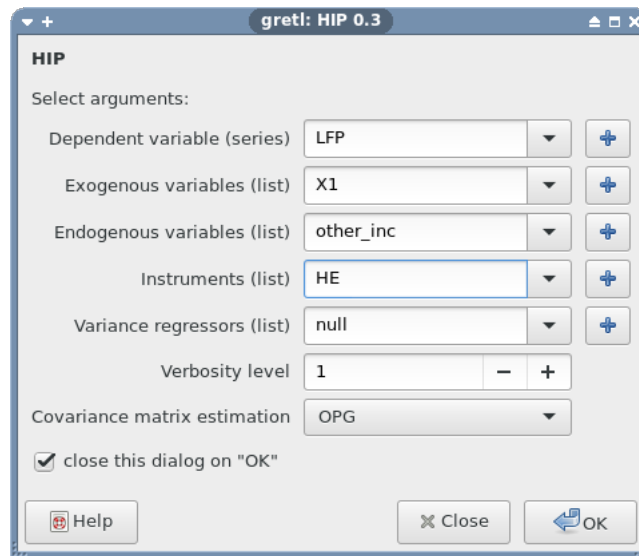


Figure 1: HIP GUI hook

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 (5th edition), which also uses Mroz’s dataset. The script goes like this:

```
include HIP.gfn

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

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

list endo = WE
list inst = WMED WFED CIT

Mitchell = HIP_setup(LFP, X, null, null, Z)

set stopwatch
HIP_estimate(&Mitchell)
```

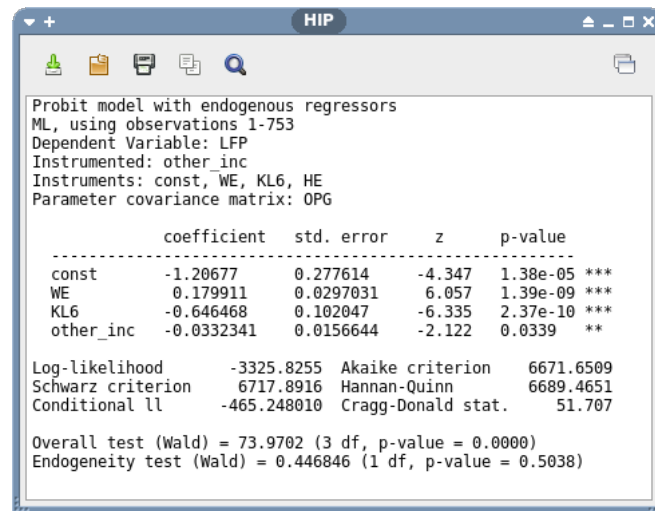


Figure 2: HIP output

```
printf "Elapsed time = %g seconds\n", $stopwatch
```

```
HIP_printout(&Mitchell, 2)
```

Note that in this case we did not use the HIP function, but instead we split its workload between three 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\_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 may be convenient, at times, because it gives you a finer control on “what happens if”. For example, the Cragg–Donald statistics gets computed during the initialization of the bundle. You may want to decide whether to proceed with estimation or not depending on how strong your instruments are.

Of course, the same can be accomplished through the GUI.

### 3.4 Let’s get HIP. Heteroskedasticity and endogeneity at the same time.

The script goes:

```
set echo off
set messages off
include HIP.gfn

open mroz87.gdt -q

list EXOG = const WA CIT K618
list ENDOG = WE
```

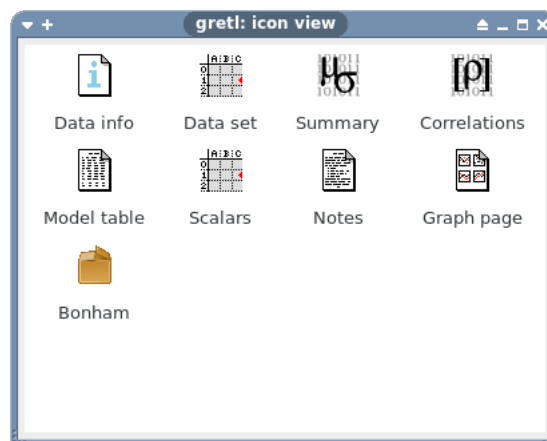


Figure 3: Icon view with a HIP bundle

```
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: y
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 example file `weak.gdt` in the examples directory. We do some heuristics, but we're not omnipotent.

## 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* 55: 765–799.
- 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 reparametrise 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 these models, we divide the loglikelihood for one observation in 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 Mill's ratio. Then,

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

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

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

## B List of functions

### B.1 Model setup

**FIXME:** THIS IS OUTDATED AT THE MOMENT AND NEEDS TO BE FIXED.

---

```
HIP_setup(series y, list EXOG, list ENDOG[null], list ADDIN[null], list HETVAR[null],
int s[0:2:0])
```

---

1. a series containing  $y_i$ , the dependent binary variable **(required)**
2. a list containing the exogenous variables  $\mathbf{X}_{1i}$  in  $\mathbf{X}_i$  in equation (1) **(required)**
3. a list containing the exogenous variables  $\mathbf{Y}_i$  in equations (1)–(2)

4. a list containing the additional instruments  $\mathbf{X}_{2i}$  in  $\mathbf{X}_i$  in equation (2)
5. a list containing the variables  $\mathbf{W}_i$  of the skedastic function in equation (1)
6. a scalar, acting as an integer, for the choice of the covariance matrix estimation method

## B.2 Estimation

---

`HIP_estimate(bundle *b)`

---

General estimation function. Its argument is:

1. the address of a model bundle created via `HIP_setup` (**required**)

## B.3 Output

Note: these functions assume that the bundle they refer to contain a model that has already been estimated. No checks are performed.

---

`HIP_printout(bundle *b, int verbose[0:1:3])`

---

Prints out a model. Its arguments are

1. the address of a model bundle filled via `HIP_estimate` (**required**)
2. a scalar, acting as a integer, to choose the verbosity: 0 = quiet, 1 = main equation, 2 = first stages, 3 = mle verbose.

## 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_estimate`
3. `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		
<b>n</b>	scalar	number of observations
<b>het</b>	scalar	acting as a Boolean switch, Heteroskedastic probit
<b>iv</b>	scalar	acting as a Boolean switch, Instrumental Variables probit
<b>T</b>	scalar	number of observations used
<b>t1</b>	scalar	first observation used
<b>t2</b>	scalar	last observation used
Data		
<b>depvar</b>	series	dependent variable
<b>mEXOG</b>	matrix	exogenous regressors
<b>mk1</b>	matrix	number of exogenous regressors
<b>mENDOg</b>	matrix	endogenous regressors
<b>mp</b>	matrix	number of endogenous regressors
<b>mADDIN</b>	matrix	additional instruments
<b>mk2</b>	matrix	number of additional instruments
<b>mHETVAR</b>	matrix	variance regressors
<b>mq</b>	matrix	number of variance regressors
<b>mZ</b>	matrix	total regressors
<b>mh</b>	matrix	number of total regressors
<b>mX</b>	matrix	total instruments
<b>mk</b>	matrix	number of total instruments
Strings		
<b>depvarname</b>	string	dependent variable name
<b>mEXOGnames</b>	string	exogenous regressors names
<b>mENDOgnames</b>	string	endogenous regressors names
<b>mADDINnames</b>	string	additional instruments names
<b>mHETVARnames</b>	string	variance regressors names
<b>mZnames</b>	string	total regressors names
<b>mXnames</b>	string	total instruments names
Estimation parameters		
<b>vcvtype</b>	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)