

# Package ‘fnets’

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**Type** Package

**Title** Factor-adjusted Network Estimation and Forecasting for High-dimensional Time Series

**Version** 0.1.0

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**Description** Implements methods for network estimation and forecasting of high-dimensional time series exhibiting strong serial and cross-sectional correlations under a factor-adjusted vector autoregressive model.

**Depends** R (>= 3.1.2)

**Imports** lpSolve,  
parallel,  
doParallel,  
foreach,  
MASS,  
fields,  
igraph,  
RColorBrewer

**License** GPL (>= 3)

**Encoding** UTF-8

**LazyData** true

**RoxygenNote** 7.1.1

## R topics documented:

common.predict . . . . .	2
fnets . . . . .	3
fnets.var . . . . .	5
hl.factor.number . . . . .	7
idio.predict . . . . .	8
npar.lrpc . . . . .	9
par.lrpc . . . . .	10
plot.fnets . . . . .	12
predict.fnets . . . . .	13
sim.common1 . . . . .	14
sim.common2 . . . . .	15
sim.var . . . . .	16
<b>Index</b>	<b>17</b>

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common.predict

*Forecasting the factor-driven common component*


---

### Description

Produces forecasts of the common component for a given forecasting horizon by estimating the best linear predictors

### Usage

```
common.predict(
  object,
  x,
  h = 1,
  common.method = c("restricted", "unrestricted"),
  r = NULL
)
```

### Arguments

object	fnets object
x	input time series matrix, with each row representing a variable
h	forecasting horizon
common.method	a string specifying the method for common component forecasting; possible values are: <ul style="list-style-type: none"> <li>"restricted" performs forecasting under a restrictive static factor model</li> <li>"unrestricted" performs forecasting under an unrestrictive, blockwise VAR representation of the common component</li> </ul>
r	number of static factors; if common.method = "restricted" and r = NULL, it is estimated as the maximiser of the ratio of the successive eigenvalues of the estimate of the common component covariance matrix, see Ahn and Horenstein (2013)

### Value

a list containing	
is	in-sample estimator of the common component
fc	forecasts of the common component for a given forecasting horizon h
r	static factor number
h	forecast horizon

### References

Barigozzi, M., Cho, H. & Owens, D. (2021) FNETS: Factor-adjusted network analysis for high-dimensional time series.

Ahn, S. C. & Horenstein, A. R. (2013) Eigenvalue ratio test for the number of factors. *Econometrica*, 81(3), 1203–1227.

Forni, M., Hallin, M., Lippi, M. & Reichlin, L. (2005). The generalized dynamic factor model: one-sided estimation and forecasting. *Journal of the American Statistical Association*, 100(471), 830–840.

Forni, M., Hallin, M., Lippi, M. & Zaffaroni, P. (2017). Dynamic factor models with infinite-dimensional factor space: Asymptotic analysis. *Journal of Econometrics*, 199(1), 74–92.

## Examples

```
set.seed(123)
n <- 500
p <- 50
common <- sim.common1(n, p)
idio <- sim.var(n, p)
x <- common$data + idio$data
out <- fnets(x, q = NULL, idio.var.order = 1, idio.method = "lasso", lrpc.method = "none")
cpre <- common.predict(out, x, h = 1, common.method = 'restricted', r = NULL)
ipre <- idio.predict(out, x, cpre, h = 1)
```

---

fnets

---

*Factor-adjusted network estimation*


---

## Description

Operating under factor-adjusted vector autoregressive (VAR) model, the function estimates the spectral density and autocovariance matrices of the factor-driven common component and the idiosyncratic VAR process, the impulse response functions and common shocks for the common component, and VAR parameters, innovation covariance matrix and long-run partial correlations for the idiosyncratic component.

## Usage

```
fnets(
  x,
  center = TRUE,
  q = NULL,
  ic.op = 5,
  kern.const = 4,
  common.args = list(var.order = NULL, max.var.order = NULL, trunc.lags = 20, n.perm =
    10),
  idio.var.order = 1,
  idio.method = c("lasso", "ds"),
  lrpc.method = c("par", "npar", "none"),
  cv.args = list(n.folds = 1, path.length = 10, do.plot = FALSE)
)
```

## Arguments

x	input time series matrix, with each row representing a variable
center	whether to de-mean the input x row-wise
q	number of factors. If q = NULL, the factor number is estimated by an information criterion-based approach of Hallin and Liška (2007), see <a href="#">hl.factor.number</a> for further details

<code>ic.op</code>	choice of the information criterion, see <a href="#">hl.factor.number</a> for further details
<code>kern.const</code>	constant multiplied to $\text{floor}((\text{dim}(x)[2]/\log(\text{dim}(x)[2]))^{(1/3)})$ which determines the kernel bandwidth for dynamic PCA
<code>common.args</code>	a list specifying the tuning parameters required for estimating the impulse response functions and common shocks. It contains: <ul style="list-style-type: none"> <li>• <code>var.order</code> order of the blockwise VAR representation of the common component. If <code>var.order = NULL</code>, it is selected blockwise by Schwarz criterion</li> <li>• <code>max.var.order</code> maximum blockwise VAR order for the Schwarz criterion</li> <li>• <code>trunc.lags</code> truncation lag for impulse response function estimation</li> <li>• <code>n.perm</code> number of cross-sectional permutations involved in impulse response function estimation</li> </ul>
<code>idio.var.order</code>	order of the idiosyncratic VAR process; if a vector of integers is supplied, the order is chosen via cross validation
<code>idio.method</code>	a string specifying the method to be adopted for idiosyncratic VAR process estimation; possible values are: <ul style="list-style-type: none"> <li>• "lasso" Lasso-type l1-regularised M-estimation</li> <li>• "ds" Dantzig Selector-type constrained l1-minimisation</li> </ul>
<code>lrpc.method</code>	a string specifying the type of estimator for long-run partial correlation matrix estimation; possible values are: <ul style="list-style-type: none"> <li>• "par" parametric estimator based on the VAR model assumption</li> <li>• "npar" nonparametric estimator from inverting the long-run covariance matrix of the idiosyncratic component via constrained l1-minimisation</li> <li>• "none" do not estimate the long-run partial correlation matrix</li> </ul>
<code>cv.args</code>	a list specifying arguments for the cross validation procedures for selecting the tuning parameters involved in VAR parameter and (long-run) partial correlation matrix estimation. It contains: <ul style="list-style-type: none"> <li>• <code>n.folds</code> number of folds</li> <li>• <code>path.length</code> number of regularisation parameter values to consider; a sequence is generated automatically based in this value</li> <li>• <code>do.plot</code> whether to plot the output of the cross validation step</li> </ul>

## Details

See Barigozzi, Cho and Owens (2021) for further details.

## Value

an S3 object of class `fnets`, which contains the following fields:

<code>q</code>	number of factors
<code>spec</code>	a list containing estimates of the spectral density matrices for <code>x</code> , common and idiosyncratic components
<code>acv</code>	a list containing estimates of the autocovariance matrices for <code>x</code> , common and idiosyncratic components
<code>common.irf</code>	if $q \geq 1$ , a list containing estimators of the impulse response functions (as an array of dimension $(p, q, \text{trunc.lags} + 2)$ ) and common shocks (an array of dimension $(q, n)$ ) for the common component
<code>idio.var</code>	a list containing the following fields:

	<ul style="list-style-type: none"> <li>• beta estimate of VAR parameter matrix; each column contains parameter estimates for the regression model for a given variable</li> <li>• Gamma estimate of the innovation covariance matrix</li> <li>• lambda regularisation parameter</li> <li>• var.order VAR order</li> </ul>
lrpc	see the output of <a href="#">par.lrpc</a> if <code>lrpc.method = 'par'</code> and that of <a href="#">npar.lrpc</a> if <code>lrpc.method = 'npar'</code>
mean.x	if <code>center = TRUE</code> , returns a vector containing row-wise sample means of <code>x</code> ; if <code>center = FALSE</code> , returns a vector of zeros
idio.method	input parameter
lrpc.method	input parameter
kern.const	input parameter

## References

Barigozzi, M., Cho, H. & Owens, D. (2021) FNETS: Factor-adjusted network analysis for high-dimensional time series.

Hallin, M. & Liška, R. (2007) Determining the number of factors in the general dynamic factor model. *Journal of the American Statistical Association*, 102(478), 603–617.

## See Also

[predict.fnets](#), [plot.fnets](#)

## Examples

```
## Not run:
set.seed(123)
n <- 500
p <- 50
common <- sim.common1(n, p)
idio <- sim.var(n, p)
x <- common$data + idio$data
out <- fnets(x, q = NULL, idio.var.order = 1, idio.method = "lasso",
  lrpc.method = "par", cv.args = list(n.folds = 1, path.length = 10, do.plot = TRUE))
pre <- predict(out, x, h = 1, common.method = 'unrestricted')
plot(out, type = 'granger', display = 'network', threshold = .05)
plot(out, type = 'lrpc', display = 'heatmap', threshold = .05)

## End(Not run)
```

---

fnets.var

11-regularised Yule-Walker estimation for VAR processes

---

## Description

Estimates the VAR parameter matrices via 11-regularised Yule-Walker estimation and innovation covariance matrix via constrained 11-minimisation.

## Usage

```
fnets.var(
  x,
  center = TRUE,
  method = c("lasso", "ds"),
  lambda = NULL,
  var.order = 1,
  cv.args = list(n.folds = 1, path.length = 10, do.plot = FALSE),
  n.iter = 100,
  tol = 0,
  n.cores = min(parallel::detectCores() - 1, 3)
)
```

## Arguments

<code>x</code>	input time series matrix, with each row representing a variable
<code>center</code>	whether to de-mean the input <code>x</code> row-wise
<code>method</code>	a string specifying the method to be adopted for VAR process estimation; possible values are: <ul style="list-style-type: none"> <li>"lasso" Lasso-type l1-regularised M-estimation</li> <li>"ds" Dantzig Selector-type constrained l1-minimisation</li> </ul>
<code>lambda</code>	regularisation parameter; if <code>lambda = NULL</code> , cross validation is employed to select the parameter
<code>var.order</code>	order of the VAR process; if a vector of integers is supplied, the order is chosen via cross validation
<code>cv.args</code>	a list specifying arguments for the cross validation procedure for selecting the regularisation parameter (and VAR order). It contains: <ul style="list-style-type: none"> <li><code>n.folds</code> number of folds</li> <li><code>path.length</code> number of regularisation parameter values to consider; a sequence is generated automatically based in this value</li> <li><code>do.plot</code> whether to plot the output of the cross validation step</li> </ul>
<code>n.iter</code>	maximum number of descent steps; applicable when <code>method = "lasso"</code>
<code>tol</code>	numerical tolerance for increases in the loss function; applicable when <code>method = "lasso"</code>
<code>n.cores</code>	number of cores to use for parallel computing, see <a href="#">makePSOCKcluster</a> ; applicable when <code>method = "ds"</code>

## Details

Further information can be found in Barigozzi, Cho and Owens (2021).

## Value

a list which contains the following fields:

<code>beta</code>	estimate of VAR parameter matrix; each column contains parameter estimates for the regression model for a given variable
<code>Gamma</code>	estimate of the innovation covariance matrix
<code>lambda</code>	regularisation parameter

var.order	VAR order
mean.x	if center = TRUE, returns a vector containing row-wise sample means of x; if center = FALSE, returns a vector of zeros

## References

Barigozzi, M., Cho, H. & Owens, D. (2021) FNETS: Factor-adjusted network analysis for high-dimensional time series.

## Examples

```
library(fnets)

set.seed(123)
n <- 500
p <- 50
idio <- sim.var(n, p)
x <- idio$data

fv <- fnets.var(x, center = TRUE, method = 'lasso', var.order = 1,
               cv.args = list(n.folds = 1, path.length = 10, do.plot = TRUE))
norm(fv$beta - t(idio$A), 'F')/norm(t(idio$A), 'F')
```

---

hl.factor.number	<i>Factor number estimator of Hallin and Liška (2007)</i>
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---

## Description

Estimates the number of factors by minimising an information criterion over sub-samples of the data. Currently the three information criteria proposed in Hallin and Liška (2007) (ic.op = 1, 2 or 3) and their variations with logarithm taken on the cost (ic.op = 4, 5 or 6) are implemented, with ic.op = 5 recommended as a default choice based on numerical experiments.

## Usage

```
hl.factor.number(x, q.max = NULL, mm, w = NULL, do.plot = FALSE, center = TRUE)
```

## Arguments

x	input time series matrix, with each row representing a variable
q.max	maximum number of factors; if q.max = NULL, a default value is selected as $\min(50, \text{floor}(\sqrt{\min(\dim(x)[2] - 1, \dim(x)[1])}))$
mm	integer representing the kernel bandwidth
w	vector of length $2 * mm + 1$ containing symmetric weights; if w = NULL, default weights are generated using the Bartlett kernel and mm
do.plot	whether to plot the values of six information criteria
center	whether to de-mean the input x row-wise

## Details

See Hallin and Liška (2007) for further details.

**Value**

	a list containing
q.hat	a vector containing minimisers of the six information criteria
Gamma_x	an array containing the estimates of the autocovariance matrices of x at $2 * mm + 1$ lags
Sigma_x	an array containing the estimates of the spectral density matrices of x at $2 * mm + 1$ Fourier frequencies
sv	a list containing the singular value decomposition of Sigma_x

**References**

Hallin, M. & Liška, R. (2007) Determining the number of factors in the general dynamic factor model. *Journal of the American Statistical Association*, 102(478), 603–617.

**Examples**

```
library(fnets)

set.seed(123)
n <- 500
p <- 50
common <- sim.common2(n, p)
idio <- sim.var(n, p)
x <- common$data * apply(idio$data, 1, sd)/apply(common$data, 1, sd) + idio$data

hl <- hl.factor.number(x, q.max = NULL, mm = floor(4 * (n/log(n))^(1/3)), do.plot = TRUE)
hl$q
```

---

idio.predict	<i>Forecasting idiosyncratic VAR process</i>
--------------	--

---

**Description**

Produces forecasts of the idiosyncratic VAR process for a given forecasting horizon by estimating the best linear predictors

**Usage**

```
idio.predict(object, x, cpre, h = 1)
```

**Arguments**

object	fnets object
x	input time series matrix, with each row representing a variable
cpre	output of <a href="#">common.predict</a>
h	forecast horizon



**Value**

a list containing

is	in-sample estimator of the idiosyncratic component
fc	forecasts of the idiosyncratic component for a given forecasting horizon h
h	forecast horizon

**References**

Barigozzi, M., Cho, H. & Owens, D. (2021) FNETS: Factor-adjusted network analysis for high-dimensional time series.

**Examples**

```
set.seed(123)
n <- 500
p <- 50
common <- sim.common1(n, p)
idio <- sim.var(n, p)
x <- common$data + idio$data
out <- fnets(x, q = NULL, idio.var.order = 1, idio.method = "lasso", lrpc.method = "none")
cpre <- common.predict(out, x, h = 1, common.method = 'restricted', r = NULL)
ipre <- idio.predict(out, x, cpre, h = 1)
```

---

npar.lrpc

---

*Nonparametric estimation of long-run partial correlations of factor-adjusted VAR processes*


---

**Description**

Returns a nonparametric estimate of long-run partial correlations of the VAR process from the inverse of long-run covariance matrix obtained via constrained l1-minimisation.

**Usage**

```
npar.lrpc(
  object,
  x,
  eta = NULL,
  cv.args = list(n.folds = 1, path.length = 10, do.plot = FALSE),
  correct.zero = TRUE,
  n.cores = min(parallel::detectCores() - 1, 3)
)
```

**Arguments**

object	fnets object
x	input time series matrix; with each row representing a variable
eta	regularisation parameter; if eta = NULL, it is selected by cross validation

cv.args	a list specifying arguments for the cross validation procedure for selecting the tuning parameter involved in long-run partial correlation matrix estimation. It contains: <ul style="list-style-type: none"> <li>• n.folds number of folds</li> <li>• path.length number of regularisation parameter values to consider; a sequence is generated automatically based in this value</li> <li>• do.plot whether to plot the output of the cross validation step</li> </ul>
correct.zero	whether to correct for any zero-entries in the diagonals of the inverse of long-run covariance matrix
n.cores	number of cores to use for parallel computing, see <a href="#">makePSOCKcluster</a>

### Value

a list containing	
Omega	estimated inverse of the long-run covariance matrix
lrpc	estimated long-run partial correlation matrix
eta	regularisation parameter

### Examples

```
## Not run:
set.seed(123)
n <- 500
p <- 50
common <- sim.common1(n, p)
idio <- sim.var(n, p)
x <- common$data + idio$data
out <- fnets(x, q = NULL, idio.method = 'lasso', lrpc.method = 'none')
nlrpc <- npar.lrpc(out, x, cv.args = list(n.folds = 1, path.length = 10, do.plot = TRUE))
out$lrpc <- nlrpc
out$lrpc.method <- 'npar'
plot(out, type = 'lrpc', display = 'heatmap', threshold = .05)

## End(Not run)
```

---

par.lrpc	<i>Parametric estimation of long-run partial correlations of factor-adjusted VAR processes</i>
----------	--

---

### Description

Returns a parametric estimate of long-run partial correlations of the VAR process from the VAR parameter estimates and the inverse of innovation covariance matrix obtained via constrained l1-minimisation.

**Usage**

```
par.lrpc(
  object,
  x,
  eta = NULL,
  cv.args = list(n.folds = 1, path.length = 10, do.plot = FALSE),
  correct.zero = TRUE,
  n.cores = min(parallel::detectCores() - 1, 3)
)
```

**Arguments**

object	fnets object
x	input time series matrix; with each row representing a variable
eta	regularisation parameter; if eta = NULL, it is selected by cross validation
cv.args	a list specifying arguments for the cross validation procedure for selecting the tuning parameter involved in long-run partial correlation matrix estimation. It contains: <ul style="list-style-type: none"> <li>• n.folds number of folds</li> <li>• path.length number of regularisation parameter values to consider; a sequence is generated automatically based in this value</li> <li>• do.plot whether to plot the output of the cross validation step</li> </ul>
correct.zero	whether to correct for any zero-entries in the diagonals of the inverse of long-run covariance matrix
n.cores	number of cores to use for parallel computing, see <a href="#">makePSOCKcluster</a>

**Details**

See Barigozzi, Cho and Owens (2021) for further details.

**Value**

a list containing

Delta	estimated inverse of the innovation covariance matrix
Omega	estimated inverse of the long-run covariance matrix
pc	estimated innovation partial correlation matrix
lrpc	estimated long-run partial correlation matrix
eta	regularisation parameter

**References**

Barigozzi, M., Cho, H. & Owens, D. (2021) FNETS: Factor-adjusted network analysis for high-dimensional time series.

## Examples

```
## Not run:
set.seed(123)
n <- 500
p <- 50
common <- sim.common1(n, p)
idio <- sim.var(n, p)
x <- common$data + idio$data
out <- fnets(x, q = NULL, idio.method = 'lasso', lrpc.method = 'none')
plrpc <- par.lrpc(out, x, cv.args = list(n.folds = 1, path.length = 10, do.plot = TRUE))
out$lrpc <- plrpc
out$lrpc.method <- 'par'
plot(out, type = 'pc', display = 'network', threshold = .05)
plot(out, type = 'lrpc', display = 'heatmap', threshold = .05)

## End(Not run)
```

---

plot.fnets

---

*Plotting the networks estimated by fnets*


---

## Description

Plotting method for S3 objects of class `fnets`. Produces a plot visualising three networks underlying factor-adjusted VAR processes: (i) directed network representing Granger causal linkages, as given by estimated VAR transition matrices aggregated across the lags, (ii) undirected network representing contemporaneous linkages after accounting for lead-lag dependence, as given by partial correlations of VAR innovations, (iii) undirected network summarising (i) and (ii) as given by long-run partial correlations of VAR processes.

## Usage

```
## S3 method for class 'fnets'
plot(
  x,
  type = c("granger", "pc", "lrpc"),
  display = c("network", "heatmap"),
  names = NA,
  groups = NA,
  threshold = 0,
  ...
)
```

## Arguments

<code>x</code>	<code>fnets</code> object
<code>type</code>	a string specifying which of the above three networks (i)–(iii) to visualise; possible values are <ul style="list-style-type: none"> <li>"granger" directed network representing Granger causal linkages</li> <li>"pc" undirected network representing contemporaneous linkages; available when <code>x\$lrpc.method = "par"</code></li> </ul>

	<ul style="list-style-type: none"> <li>• "lrpc" undirected network summarising Granger causal and contemporaneous linkages; available when <code>x\$lrpc.method = "par"</code> or <code>x\$lrpc.method = "npar"</code></li> </ul>
display	a string specifying how to visualise the network; possible values are: <ul style="list-style-type: none"> <li>• "network" as an igraph object, see <a href="#">plot.igraph</a></li> <li>• "heatmap" as a heatmap, see <a href="#">imagePlot</a></li> </ul>
names	a character vector containing the names of the vertices
groups	an integer vector denoting any group structure of the vertices
threshold	if <code>threshold &gt; 0</code> , hard thresholding is performed on the matrix giving rise to the network of interest
...	additional arguments

### Details

See Barigozzi, Cho and Owens (2021) for further details.

### References

Barigozzi, M., Cho, H. & Owens, D. (2021) FNETS: Factor-adjusted network analysis for high-dimensional time series.

### See Also

[fnets](#)

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predict.fnets	<i>Forecasting by fnets</i>
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---

### Description

Produces forecasts of the data for a given forecasting horizon by separately estimating the best linear predictors of common and idiosyncratic components

### Usage

```
## S3 method for class 'fnets'
predict(
  object,
  x,
  h = 1,
  common.method = c("restricted", "unrestricted"),
  r = NULL,
  ...
)
```

**Arguments**

object	fnets object
x	input time series matrix, with each row representing a variable
h	forecasting horizon
common.method	a string specifying the method for common component forecasting; possible values are: <ul style="list-style-type: none"> <li>• "restricted" performs forecasting under a restrictive static factor model</li> <li>• "unrestricted" performs forecasting under an unrestrictive, blockwise VAR representation of the common component</li> </ul>
r	number of static factors; if common.method = "restricted" and r = NULL, it is estimated as the maximiser of the ratio of the successive eigenvalues of the estimate of the common component covariance matrix, see Ahn and Horenstein (2013)
...	not used

**Value**

a list containing	
forecast	forecasts for the given forecasting horizon
common.pred	a list containing forecasting results for the common component
idio.pred	a list containing forecasting results for the idiosyncratic component
mean.x	mean.x argument from object

**References**

Barigozzi, M., Cho, H. & Owens, D. (2021) FNETS: Factor-adjusted network analysis for high-dimensional time series.

Ahn, S. C. & Horenstein, A. R. (2013) Eigenvalue ratio test for the number of factors. *Econometrica*, 81(3), 1203–1227.

**See Also**

[fnets](#), [common.predict](#), [idio.predict](#)

---

sim.common1

---

*Simulate data from a dynamic factor model*


---

**Description**

Simulate the common component following a dynamic factor model that does not admit a static representation; see the model (C1) in the reference.

**Usage**

```
sim.common1(n, p, q = 2, heavy = FALSE)
```

**Arguments**

n	sample size
p	dimension
q	number of dynamic factors
heavy	if heavy = FALSE, common shocks are generated from rnorm whereas if heavy = TRUE, from rt with df = 5 and then scaled by $\sqrt{3/5}$

**Value**

a list containing	
data	generated series
q	number of factors

**References**

Barigozzi, M., Cho, H. & Owens, D. (2021) FNETS: Factor-adjusted network analysis for high-dimensional time series.

**Examples**

```
common <- sim.common1(500, 50)
```

---

sim.common2	<i>Simulate data from a static factor model</i>
-------------	---

---

**Description**

Simulate the common component following a dynamic factor model that admits a static representation; see the model (C2) in the reference.

**Usage**

```
sim.common2(n, p, q = 2, heavy = FALSE)
```

**Arguments**

n	sample size
p	dimension
q	number of dynamic factors; number of static factors is given by $2 * q$
heavy	if heavy = FALSE, common shocks are generated from rnorm whereas if heavy = TRUE, from rt with df = 5 and then scaled by $\sqrt{3/5}$

**Value**

a list containing	
data	generated series
q	number of factors
r	number of static factors

## References

Barigozzi, M., Cho, H. & Owens, D. (2021) FNETS: Factor-adjusted network analysis for high-dimensional time series.

## Examples

```
common <- sim.common2(500, 50)
```

---

sim.var	<i>Simulate a VAR(1) process</i>
---------	----------------------------------

---

## Description

Simulate a VAR(1) process; see the reference for the generation of the transition matrix.

## Usage

```
sim.var(n, p, Gamma = diag(1, p), heavy = FALSE)
```

## Arguments

n	sample size
p	dimension
Gamma	innovation covariance matrix; ignored if heavy = TRUE
heavy	if heavy = FALSE, common shocks are generated from <code>rnorm</code> whereas if heavy = TRUE, from <code>rt</code> with <code>df = 5</code> and then scaled by <code>sqrt(3 / 5)</code>

## Value

	a list containing
data	generated series
A	transition matrix
Gamma	innovation covariance matrix

## References

Barigozzi, M., Cho, H. & Owens, D. (2021) FNETS: Factor-adjusted network analysis for high-dimensional time series.

## Examples

```
idio <- sim.var(500, 50)
```



# Index

`common.predict`, [2](#), [8](#), [14](#)

`fnets`, [3](#), [13](#), [14](#)

`fnets.var`, [5](#)

`hl.factor.number`, [3](#), [4](#), [7](#)

`idio.predict`, [8](#), [14](#)

`imagePlot`, [13](#)

`makePSOCKcluster`, [6](#), [10](#), [11](#)

`npar.lrpc`, [5](#), [9](#)

`par.lrpc`, [5](#), [10](#)

`plot.fnets`, [5](#), [12](#)

`plot.igraph`, [13](#)

`predict.fnets`, [5](#), [13](#)

`sim.common1`, [14](#)

`sim.common2`, [15](#)

`sim.var`, [16](#)