

# The Dynare Macro Processor

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# Outline

- 1 Overview
- 2 Syntax
- 3 Common uses

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# Motivation

- The **Dynare language** (used in `.mod` files) is well suited for many economic models
  - ▶ It's a markup language that defines models
  - ▶ Lacks a programmatic element
- The **Dynare macro language** adds a programmatic element to Dynare
  - ▶ Introduces conditionals, loops, and other simple programmatic directives
  - ▶ Used to speed up model development
  - ▶ Useful in various situations
    - ★ Multi-country models
    - ★ Creation of modular `.mod` files
    - ★ Variable flipping
    - ★ Conditional inclusion of equations
    - ★ ...among others

# Design of the macro language

- The Dynare macro language provides a set of **macro commands** that can be used in .mod files
- The macro processor transforms a .mod file with macro commands into a .mod file without macro commands (doing text expansions/inclusions) and then feeds it to the Dynare parser
- The key point to understand is that the macro processor only does **text substitution** (like the C preprocessor or the PHP language)

# Dynare Flowchart



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# Macro Directives

- Directives begin with: `@#`
- A directive gives instructions to the macro processor
- Main directives are:
  - ▶ file inclusion: `@#include`
  - ▶ definition of a macro processor variable or function: `@#define`
  - ▶ conditional statements: `@#if/@#ifdef/@#ifndef/@#else/@#elseif/@#endif`
  - ▶ loop statements: `@#for/@#endfor`
- Most directives fit on one line. If needed however, two backslashes (*i.e.* `\\`) at the end of a line indicate that the directive is continued on the next line.
- Directives are not terminated with a semicolon



# Values

- The macro processor can handle values of 5 different types:
  - ① boolean (logical value, true or false)
  - ② real (double precision floating point number)
  - ③ string (of characters)
  - ④ tuple
  - ⑤ array
- Values of the types listed above can be cast to other types
  - ▶ `(real) "3.1" → 3.1`
  - ▶ `(string) 3.1 → "3.1"`
  - ▶ `(array) 4 → [4]`
  - ▶ `(real) [5] → 5`
  - ▶ `(real) [6, 7] → error`
  - ▶ `(bool) -1 && (bool) 2 → true`

# Macro-expressions (1/8)

- Macro-expressions are constructed using literals (*i.e.* fixed values) of the 5 basic types described above, macro-variables, standard operators, function calls and comprehensions.
- Macro-expressions can be used in two places:
  - ▶ inside macro directives; no special markup is required
  - ▶ in the body of the `.mod` file, between an “at”-sign and curly braces (like `@{expr}`); the macro processor will substitute the expression with its value

## Macro-expressions (2/8): Boolean

Boolean literals are `true` and `false`.

### Operators on booleans

- comparison operators: `==` `!=`
- logical operators:
  - ▶ conjunction (“and”): `&&`
  - ▶ disjunction (“or”): `||`
  - ▶ negation (“not”): `!`

# Macro-expressions (3/8): Real

## Operators on reals

- arithmetic operators: `+` `-` `*` `/` `^`
- comparison operators: `<` `>` `<=` `>=` `==` `!=`
- logical operators: `&&` `||` `!`
- range with unit increment: `1:4` is equivalent to real array `[1, 2, 3, 4]`  
(NB: `[1:4]` is equivalent to an array containing an array of reals, *i.e.* `[[1, 2, 3, 4]]`)
- range with user-defined increment:  
`4:-1.1:-1` is equivalent to real array `[4, 2.9, 1.8, 0.7, -0.4]`

## Functions for reals

- `min`, `max`, `exp`, `ln` (or `log`), `log10`
- `sign`, `floor`, `ceil`, `trunc`, `round`, `mod`
- `sin`, `cos`, `tan`, `asin`, `acos`, `atan`
- `sqrt`, `cbirt`, `erf`, `erfc`, `normpdf`, `normcdf`, `gamma`, `lgamma`

## Macro-expressions (4/8): String

String literals have to be declared between *double* quotes, e.g. "string"

### Operators on character strings

- comparison operators: < > <= >= == !=
- concatenation: +
- string length: length()
- string emptiness: isempty()
- extraction of substrings: if *s* is a string, then one can write *s*[3] or *s*[4:6]

## Macro-expressions (5/8): Tuple

Tuples are enclosed by parentheses and elements are separated by commas (like (a,b,c) or (1,2.2,c)).

### Operators on tuples

- comparison operators: `==` `!=`
- functions: `length()`, `isempty()`
- testing membership in tuple: `in` operator  
(example: `"b" in ("a", "b", "c")` returns `true`)

## Macro-expressions (6/8): Array (1/2)

Arrays are enclosed by brackets, and their elements are separated by commas (like `[1, [2,3], 4]` or `["US", "EA"]`).

### Operators on arrays

- comparison operators: `==` `!=`
- dereferencing: if `v` is an array, then `v[2]` is its 2<sup>nd</sup> element
- concatenation: `+`
- functions: `sum()`, `length()`, `isempty()`
- extraction of sub-arrays: e.g. `v[4:6]`
- testing membership of an array: `in` operator  
(example: `"b" in ["a", "b", "c"]` returns `true`)

## Macro-expressions (6/8): Array (2/2)

Arrays can be seen as representing a set of elements (assuming no element appears twice in the array). Several set operations can thus be performed on arrays: union, intersection, difference, Cartesian product and power.

### Set operations on arrays

- set union:  $|$
- set intersection:  $\&$
- set difference:  $-$
- Cartesian product of two arrays:  $*$
- Cartesian power of an array:  $^$

For example: if  $A$  and  $B$  are arrays, then the following set operations are valid:  $A|B$ ,  $A\&B$ ,  $A-B$ ,  $A*B$ ,  $A^3$ .

NB: the array resulting from Cartesian product or power has tuples as its elements.



## Macro-expressions (7/8): Comprehension (1/3)

Comprehensions are a shorthand way of creating arrays from other arrays. This is done by filtering, mapping, or both.

### Filtering

- Allows one to choose those elements from an array for which a condition holds
- Syntax: `[ variable/tuple in array when condition ]`
- Example: Choose even numbers from array
  - ▶ Code: `[ i in 1:5 when mod(i,2) == 0 ]`
  - ▶ Result: `[2, 4]`

## Macro-expressions (7/8): Comprehension (2/3)

### Mapping

- Allows one to apply a transformation to every element of an array
- Syntax: `[ expr for variable/tuple in array ]`
- Example: Square elements in array
  - ▶ Code: `[ i^2 for i in 1:5 ]`
  - ▶ Result: `[1, 4, 9, 16, 25]`
- Example: Swap pairs of an array
  - ▶ Code: `[ (j,i) for (i,j) in (1:2)^2 ]`
  - ▶ Result: `[(1, 1), (2, 1), (1, 2), (2, 2)]`

## Macro-expressions (7/8): Comprehension (3/3)

### Mapping and Filtering

- Allows one to apply a transformation to the elements selected from an array
- Syntax: `[ expr for variable/tuple in array when condition ]`
- Example: Square of odd numbers between 1 and 5
  - ▶ Code: `[ i^2 for i in 1:5 when mod(i,2) == 1 ]`
  - ▶ Result: `[1, 9, 25]`

## Macro-expressions (8/8): Functions

- Can take any number of arguments
- Dynamic binding: is evaluated when invoked during the macroprocessing stage, not when defined
- Can be included in expressions; valid operators depend on return type

### Declaration syntax

```
@#define function_signature = expression
```

### Example

If we declare the following function:

```
@#define distance(x, y) = sqrt(x^2 + y^2)
```

Then `distance(3, 4)` will be equivalent to 5.

## Defining macro-variables (1/2)

The value of a macro-variable can be defined with the `@#define` directive.

The macro processor has its own list of variables, which are different from model variables and MATLAB/Octave variables

### Syntax

```
@#define variable_name = expression
```

### Examples

```
@#define x = 5           // Real
#define y = "US"         // String
#define v = [ 1, 2, 4 ]  // Real array
#define w = [ "US", "EA" ] // String array
#define z = 3 + v[2]     // Equals 5
#define t = ("US" in w)  // Equals true
```

## Defining macro-variables (2/2)

Macro variables can also be defined on the Dynare command line by using the `-D` option, for easily switching between different flavours of a model.

### Example 1

```
dynare myfile.mod -Dx=5
```

The macro-variable `x` will be equal to 5 when running `myfile.mod`.

### Example 2

Use single quotes around the `-D` option when there are spaces or special characters in the variable definition.

```
dynare myfile.mod '-DA=[ i in [1,2,3] when i > 1 ]'
```

The macro-variable `A` will be equal to `[2,3]` when running `myfile.mod`.

# Expression substitution

## Dummy example

### Before macro processing

```
@#define x = 1
@#define y = [ "B", "C" ]
@#define i = 2
@#define f(x) = x + " + " + y[i]
@#define i = 1

model;
  A = @{y[i] + f("D")};
end;
```

### After macro processing

```
model;
  A = BD + B;
end;
```

## Include directive (1/2)

- This directive simply inserts the text of another file in its place

### Syntax

```
@#include "filename"
```

### Example

```
@#include "modelcomponent.mod"
```

- Equivalent to a copy/paste of the content of the included file
- Note that it is possible to nest includes (*i.e.* to include a file with an included file)



## Include directive (2/2)

- The filename can be given by a macro-variable (useful in loops):

### Example with variable

```
@#define fname = "modelcomponent.mod"  
@#include fname
```

- Files to include are searched for in the current directory. Other directories can be added with the `@#includepath` directive, the `-I` command line option, or the `[paths]` section in config files.

# Loop directive (1/4)

## Syntax 1: Simple iteration over one variable

```
@#for variable_name in array_expr  
    loop_body  
@#endfor
```

## Syntax 2: Iteration over several variables at the same time

```
@#for tuple in array_expr  
    loop_body  
@#endfor
```

## Syntax 3: Iteration with some values excluded

```
@#for tuple_or_variable in array_expr when expr  
    loop_body  
@#endfor
```

## Loop directive (2/4)

### Example: before macro processing

```
model;  
@#for country in [ "home", "foreign" ]  
    GDP_@{country} = A * K_@{country}^a * L_@{country}^(1-a);  
@#endfor  
end;
```

### Example: after macro processing

```
model;  
    GDP_home = A * K_home^a * L_home^(1-a);  
    GDP_foreign = A * K_foreign^a * L_foreign^(1-a);  
end;
```

## Loop directive (3/4)

### Example: loop over several variables

```
@#define A = [ "X", "Y", "Z"]  
@#define B = [ 1, 2, 3]
```

```
model;  
@#for (i,j) in A*B  
    e_{i}_{j} = ...  
@#endfor  
end;
```

This will loop over  $e_{X_1}$ ,  $e_{X_2}$ , ...,  $e_{Z_3}$  (9 variables in total)

## Loop directive (4/4)

### Example: loop over several variables with filtering

```
model;  
@#for (i,j,k) in (1:10)^3 when i^2+j^2==k^2  
    e_{i}_{j}_{k} = ...  
@#endfor  
end;
```

This loop will iterate over only 4 triplets: (3,4,5), (4,3,5), (6,8,10), (8,6,10).

# Conditional directives (1/3)

## Syntax 1

```
@#if bool_or_real_expr  
    body included if expr is true (or != 0)  
@#endif
```

## Syntax 2

```
@#if bool_or_real_expr  
    body included if expr is true (or != 0)  
@#else  
    body included if expr is false (or 0)  
@#endif
```

## Conditional directives (2/3)

### Syntax 3

```
@#if bool_or_real_expr1
    body included if expr1 is true (or != 0)
@#elseif bool_or_real_expr2
    body included if expr2 is true (or != 0)
@#else
    body included if expr1 and expr2 are false (or 0)
@#endif
```

### Example: alternative monetary policy rules

```
@#define linear_mon_pol = false // or 0
...
model;
@#if linear_mon_pol
     $i = w \cdot i(-1) + (1-w) \cdot i_{ss} + w2 \cdot (\pi - \pi^{star});$ 
@#else
     $i = i(-1)^w \cdot i_{ss}^{(1-w)} \cdot (\pi / \pi^{star})^{w2};$ 
@#endif
...
end;
```

## Conditional directives (3/3)

### Syntax 1

```
@#ifdef variable_name  
    body included if variable defined  
@#endif
```

### Syntax 2

```
@#ifdef variable_name  
    body included if variable defined  
@#else  
    body included if variable not defined  
@#endif
```

- There is also `@#ifndef`, which is the opposite of `@#ifdef` (*i.e.* it tests whether a variable is *not* defined).
- NB: There is *no* `@#elseifdef` or `@#elseifndef` directive; use `elseif defined(variable_name)` to achieve the desired objective.



## Echo directives

- The echo directive will simply display a message on standard output
- The echomacrovars directive will display all of the macro variables (or those specified) and their values
- The save option allows saving this information to `options_.macrovars_line_x`, where `x` denotes the line number where the statement was encountered

### Syntax

```
@#echo string_expr
```

```
@#echomacrovars
```

```
@#echomacrovars list_of_variables
```

```
@#echomacrovars(save)
```

```
@#echomacrovars(save) list_of_variables
```

### Examples

```
@#echo "Information message."
```

# Error directive

- The error directive will display the message and make Dynare stop (only makes sense inside a conditional directive)

## Syntax

```
@#error string_expr
```

## Example

```
@#error "Error message!"
```

## Macro-related command line options

- `savemacro`: Useful for debugging or learning purposes, saves the output of the macro processor. If your `.mod` file is called `file.mod`, the output is saved to `file_macroexp.mod`.
- NB: `savemacro=filename` allows a user-defined file name
- `linemacro`: In the output of `savemacro`, print line numbers where the macro directives were placed.
- `onlymacro`: Stops processing after the macro processing step.

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# Modularization

- The `@#include` directive can be used to split `.mod` files into several modular components
- Example setup:
  - `modeldesc.mod`: contains variable declarations, model equations, and shock declarations
  - `simulate.mod`: includes `modeldesc.mod`, calibrates parameters, and runs stochastic simulations
  - `estim.mod`: includes `modeldesc.mod`, declares priors on parameters, and runs Bayesian estimation
- Dynare can be called on `simulate.mod` and `estim.mod`
- But it makes no sense to run it on `modeldesc.mod`
- Advantage: no need to manually copy/paste the whole model (during initial development) or port model changes (during development)

# Indexed sums or products

Example: moving average

## Before macro processing

```
@#define window = 2

var x MA_x;
...
model;
...
MA_x = @{1/(2*window+1)}*(
    @#for i in -window:window
        +x(@{i})
    @#endfor
);
...
end;
```

## After macro processing

```
var x MA_x;
...
model;
...
MA_x = 1/5*(
    +x(-2)
    +x(-1)
    +x(0)
    +x(1)
    +x(2)
);
...
end;
```

# Multi-country models

## .mod file skeleton example

```
@#define countries = [ "US", "EA", "AS", "JP", "RC" ]
@#define nth_co = "US"

@#for co in countries
var Y_@{co} K_@{co} L_@{co} i_@{co} E_@{co} ...;
parameters a_@{co} ...;
varexo ...;
@#endfor

model;
@#for co in countries
  Y_@{co} = K_@{co}^a_@{co} * L_@{co}^(1-a_@{co});
  ...
@# if co != nth_co
  (1+i_@{co}) = (1+i_@{nth_co}) * E_@{co}(+1) / E_@{co}; // UIP relation
@# else
  E_@{co} = 1;
@# endif
@#endfor
end;
```

## Endogeneizing parameters (1/4)

- When calibrating the model, it may be useful to pin down parameters by targeting endogenous objects
- Example:

$$y_t = \left( \alpha^{\frac{1}{\xi}} \ell_t^{1-\frac{1}{\xi}} + (1-\alpha)^{\frac{1}{\xi}} k_t^{1-\frac{1}{\xi}} \right)^{\frac{\xi}{\xi-1}}$$
$$lab\_rat_t = \frac{w_t \ell_t}{p_t y_t}$$

- In the model,  $\alpha$  is a (share) parameter, and  $lab\_rat_t$  is an endogenous variable
- We observe that:
  - ▶ setting a value for  $\alpha$  is not straightforward!
  - ▶ but we have real world data for  $lab\_rat_t$
  - ▶ it is clear that these two objects are economically linked



## Endogeneizing parameters (2/4)

- Therefore, when computing the steady state by solving the static model:
  - ▶ we make  $\alpha$  a variable and the steady state value  $lab\_rat$  of the dynamic variable  $lab\_rat_t$  a parameter
  - ▶ we impose an economically sensible value for  $lab\_rat$
  - ▶ the solution algorithm deduces the implied value for  $\alpha$
- We call this method “variable flipping”, because it treats  $\alpha$  as a variable and  $lab\_rat$  as a parameter for the purpose of the static model

# Endogeneizing parameters (3/4)

## Example implementation

- File `modeqs.mod`:
  - ▶ contains variable declarations and model equations
  - ▶ For declaration of `alpha` and `lab_rat`:

```
@#if steady
  var alpha;
  parameter lab_rat;
@#else
  parameter alpha;
  var lab_rat;
@#endif
```

# Endogeneizing parameters (4/4)

## Example implementation

- File `steadystate.mod`:
  - ▶ begins with `@#define steady = true`
  - ▶ followed by `@#include "modeqs.mod"`
  - ▶ initializes parameters (including `lab_rat`, excluding `alpha`)
  - ▶ computes steady state (using guess values for endogenous, including `alpha`)
  - ▶ saves values of parameters and variables at steady-state in a file, using the `save_params_and_steady_state` command
- File `simulate.mod`:
  - ▶ begins with `@#define steady = false`
  - ▶ followed by `@#include "modeqs.mod"`
  - ▶ loads values of parameters and variables at steady-state from file, using the `load_params_and_steady_state` command
  - ▶ computes simulations

## MATLAB/Octave loops vs macro processor loops (1/3)

Suppose you have a model with a parameter  $\rho$ , and you want to make simulations for three values:  $\rho = 0.8, 0.9, 1$ . There are several ways of doing this:

### With a MATLAB/Octave loop

```
rhos = [ 0.8, 0.9, 1];  
for i = 1:length(rhos)  
    set_param_value('rho',rhos(i));  
    stoch_simul(order=1);  
    if info(1)~=0  
        error('Simulation failed for parameter draw')  
    end  
end
```

- The loop is not unrolled
- MATLAB/Octave manages the iterations
- NB: always check whether the error flag `info(1)==0` to prevent erroneously relying on stale results from previous iterations

## MATLAB/Octave loops vs macro processor loops (2/3)

### With a macro processor loop (case 1)

```
rhos = [ 0.8, 0.9, 1];  
@#for i in 1:3  
    set_param_value('rho',rhos(@{i}));  
    stoch_simul(order=1);  
    if info(1)~=0  
        error('Simulation failed for parameter draw')  
    end  
@#endfor
```

- Very similar to previous example
- Loop is unrolled
- Dynare macro processor manages the loop index but not the data array (rhos)

## MATLAB/Octave loops vs macro processor loops (3/3)

### With a macro processor loop (case 2)

```
@#for rho_val in [ 0.8, 0.9, 1]
    set_param_value('rho',{rho_val});
    stoch_simul(order=1);
    if info(1)~=0
        error('Simulation failed for parameter draw')
    end
@#endfor
```

- Shorter syntax, since list of values directly given in the loop construct
- NB: Array not stored as MATLAB/Octave variable, hence cannot be used in MATLAB/Octave

Thanks for your attention!  
Questions?

My email: `sebastien@dynare.org`



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