

# The Dynare Macro Processor

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# Outline

1 Overview

2 Syntax

3 Common uses

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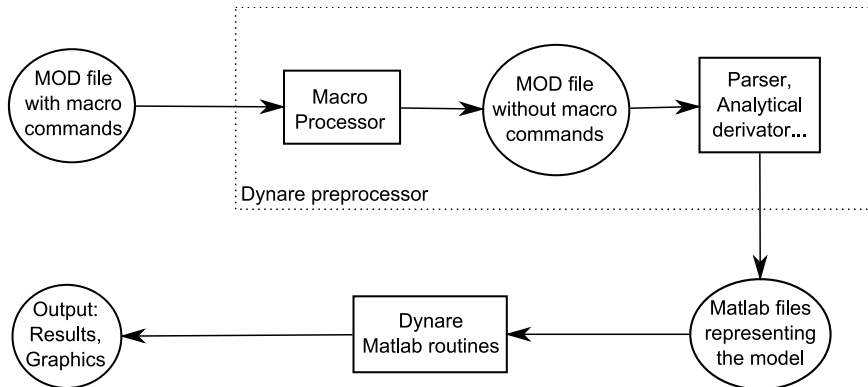
# Motivation

- 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 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 new 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: `@#define`
  - ▶ conditional statements: `@#if/@#ifdef/@#ifndef/@#else/@#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.



# Variables

- The macro processor has its own list of variables which are different than model variables and MATLAB/Octave variables
- There are 6 types of macro-variables:
  - ▶ boolean
  - ▶ real
  - ▶ string
  - ▶ tuple
  - ▶ array
  - ▶ function
- Variables/literals of the types listed above can be cast to other types
  - ▶ `(bool) -1 && (bool) 2 → true`
  - ▶ `(real) "3.1" → 3.1`
  - ▶ `(array) 4 → [4]`
  - ▶ `(real) [5] → 5`
  - ▶ `(real) [6, 7] → error`

# Macro-expressions (1/8)

- Macro-expressions are constructed using literals of the 6 basic types described above, macro-variables, comprehensions, and standard operators.
- 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

It is possible to construct macro-expressions using standard operators.

## Operators on booleans

- comparison operators: `==` `!=`
- logical operators: `&&` `||` `!`

# Macro-expressions (3/8): Real

## Operators on reals

- arithmetic operators: `+` `-` `*` `/` `^`
- comparison operators: `<` `>` `<=` `>=` `==` `!=`
- logical operators: `&&` `||` `!`
- range with increment of 1: `1:4` is equivalent to real array `[1, 2, 3, 4]`. NB `[1:4]` is equivalent to an array containing an array of reals `[[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`
- `sin`, `cos`, `tan`, `asin`, `acos`, `atan`
- `sqrt`, `cbirt`, `sign`, `floor`, `ceil`, `trunc`, `mod`
- `erf`, `erfc`, `normpdf`, `normcdf`, `gamma`, `lgamma`, `round`

## 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 parenthesis and elements 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 1)

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

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`
- difference `-`: returns the first operand from which the elements of the second operand have been removed
- Cartesian product of two arrays: `*`
- Cartesian product of one array `N` times: `^N`
- extraction of sub-arrays: e.g. `v[4:6]`
- testing membership of an array: `in` operator  
(example: `"b" in ["a", "b", "c"]` returns 1)

# 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 filtering and mapping

## 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: Reverse order of elements in 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 odd numbers from array
  - ▶ 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, not when defined
- Can be included in expressions; valid operators depend on return type

# Define directive

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

## 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 1 (true)
@#define f(x) = " " + x + y  // Function f with argument x
```

NB: You can define macro variables on the dynare command line by using the `-D` option

# 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 file.

# Loop directive (1/2)

## Syntax 1

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

## Syntax 2

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

## Syntax 3

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



## Loop directive (2/2)

### 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;
```

# 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  
     $i = w*i(-1) + (1-w)*i_{ss} + w2*(\pi - \pi^{star});$   
@#else  
     $i = i(-1)^w * i_{ss}^{(1-w)} * (\pi / \pi^{star})^w;$   
@#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 and error directives

- The echo directive will simply display a message on standard output
- The error directive will display the message and make Dynare stop (only makes sense inside a conditional directive)
- The echomacrovars directive will display all of the macro variables (or those specified) and their values, optionally saving them

### Syntax

```
@#echo string_expr  
@#error string_expr  
@#echomacrovars  
@#echomacrovars list_of_variables  
@#echomacrovars (save)  
@#echomacrovars (save) list_of_variables
```

### Examples

```
@#echo "Information message."  
@#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`.
- `nolinemacro`: In the output of `savemacro`, don't print line numbers where the macro directives were placed.
- `noemptylinemacro`: Remove empty lines in the output of `savemacro`.
- `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 shocks 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 (at the beginning) or changes to the model (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 consider a parameter as an endogenous (and vice-versa)
- Example:

$$y = \left( \alpha^{\frac{1}{\xi}} \ell^{1-\frac{1}{\xi}} + (1 - \alpha)^{\frac{1}{\xi}} k^{1-\frac{1}{\xi}} \right)^{\frac{\xi}{\xi-1}}$$
$$lab\_rat = \frac{w\ell}{py}$$

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

# Endogeneizing parameters (2/4)

- Therefore, when computing the steady state:
  - ▶ we make  $\alpha$  an endogenous variable and *lab\_rat* a parameter
  - ▶ we impose an economically relevant value for *lab\_rat*
  - ▶ the solution algorithm deduces the implied value for  $\alpha$
- We call this method “variable flipping”

# 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`
  - ▶ then with `@#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 endogenous at steady-state in a file, using the `save_params_and_steady_state` command
- File `simulate.mod`:
  - ▶ begins with `@#define steady = false`
  - ▶ then with `@#include "modeqs.mod"`
  - ▶ loads values of parameters and endogenous 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)  
    rho = rhos(i);  
    stoch_simul(order=1);  
end
```

- The loop is not unrolled
- MATLAB/Octave manages the 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  
    rho = rhos(@{i});  
    stoch_simul(order=1);  
@#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]
    rho = @{rho_val};
    stoch_simul(order=1);
@#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?