The Dynare Macro Processor

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Outline

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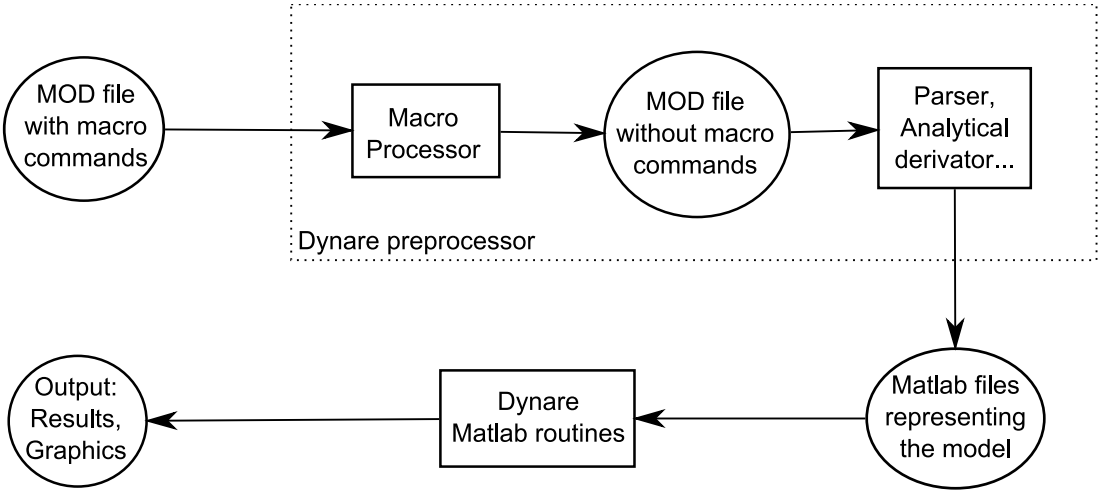
Motivation

- 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



Outline

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`, `cbrt`, `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^{nd} 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*i(-1) + (1-w)*i_ss + w2*(pie-piestar);
@#else
  i = i(-1)^w * i_ss^(1-w) * (pie/piestar)^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.

Outline

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, α is a (share) parameter, and lab_rat_t is an endogenous variable
- We observe that:
  - setting a value for α 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 α 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 α
- We call this method "variable flipping", because it treats α 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 ρ, 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?

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