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Cobwood: Enhancing Forest Economics Model Reusability Through Labelled Panel Data Structures

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Summary

Forest Sector Models provide quantitative insights into how policy changes, resource scarcity or climate impacts propagate through international forest products markets. These models balance demand, trade and wood supply in each country and project future market dynamics over decades. The cobwood package provides a labelled data structure that enhances code clarity and facilitates model inspection compared to traditional approaches. To demonstrate cobwood's application, we reimplement a simplified cobweb version of the Global Forest Products Model (GFPMx). The reusable data structure positions cobwood as an ideal component for integration into a greater modelling tool chain.

Statement of need

Trees grow over decades or centuries and wood markets can be very localized. Yet markets for processed wood and paper products are interconnected through global trade networks. To simulate the future condition of wood markets, forest economists rely on macroeconomic forest sector models. These models operate in static and dynamic phases. The static phase balances supply and demand within a year. The dynamic phase projects future demand and supply driven by exogenous factors like GDP growth and changes in the forest stock.

Several global forest sector models currently exist, including the Global Forest Products Model (GFPM) (Buongiorno et al., 2003), the European Forest Institute Global Trade Model (EFI-GTM) (Kallio et al., 2004), the Global Biosphere Management Model (GLOBIOM) (Lauri et al., 2014), the Global Forest Trade Model (GFTM) (Jonsson et al., 2015) and the Timber market Model for policy-Based Analysis (TiMBA) (TI-FSM et al., 2025). There are also multiple regional and national forest sector models.

These models are well documented, but the descriptions of variables and units are stored as external metadata, rather than within the model objects themselves. Cobwood instead organizes forest sector datasets as labelled multi-dimensional arrays with explicit country, product, and year dimensions. Metadata and dimension names are stored directly within datasets (both in memory and on disk), making model inputs and outputs easier to interpret and reuse programmatically.

Existing modelling software typically relies on ad-hoc input file management to distinguish scenarios, with scenario assumptions scattered across multiple data files, in the input file name itself, or in separate Excel sheets. Cobwood uses scenario configuration files, improving reproducibility and enabling transparent version control of modeling assumptions.

By standardizing data representation and exposing model internals, cobwood facilitates collaboration beyond forest economics. Adjacent fields such as forest management, vegetation dynamics, and life cycle analysis rely on projections of roundwood harvest and wood products consumption. An interoperable Python package enables these communities to reuse and extend existing models to simulate new drivers and analyze new policy questions.

Data structure and implementation

Figure 1 illustrates the data structure:

- Global consumption, production, trade flows, and prices for all countries, all years and for each forest product are stored as an Xarray dataset (e.g., `model["sawn"]` for sawnwood)
- Within each dataset for one product, specific variables are accessible as two-dimensional arrays with country and year coordinates (e.g., `model["sawn"]["cons"]` for consumption)
- To explore available variables, users can access the `variables` property

  ```
  model["sawn"].variables
  ```

- Array properties are used to store metadata, the example below displays the roundwood production unit:

  ```
  model["indround"]["prod"].unit
  # '1000m3'
  ```

The cobwood model has been used to produce published scenario analyses (Rougieux et al., 2024, 2025). The first model programmed inside cobwood is a reimplementation of GFPMx (Buongiorno, 2021), a version of the GFPM that uses a cobweb representation where consumption C_{ikt} responds to lagged prices $P_{ik,t-1}$ and to GDP Y_{it} in the current period. α_{ik} is a constant parameter, β_{ik} is the price elasticity and γ_{ik} the GDP elasticity of demand:

$$C_{ikt} = \alpha_{ik} \, P_{ik,t-1}^{\beta_{ik}} \, Y_{it}^{\gamma_{ik}}$$

Labelled data arrays allow developers to write Python functions that closely mirror the mathematical equations found in the academic paper describing the model, with country i and time t dimensions (products k have their own dataset, so that dimension is omitted in the code below). For example the demand function in `cobwood/gfpmx_equations.py` is implemented on an `xarray` dataset `ds` where an explanatory variable such as GDP is selected for all countries at time t with `ds["gdp"].loc[ds.c, t]`:

```python
def consumption(ds: xarray.Dataset, t: int) -> xarray.DataArray:
    """Compute consumption equation 1"""
    return (
        ds["cons_constant"]
        * pow(ds["price"].loc[ds.c, t - 1], ds["cons_price_elasticity"])
        * pow(ds["gdp"].loc[ds.c, t], ds["cons_gdp_elasticity"])
    )
```

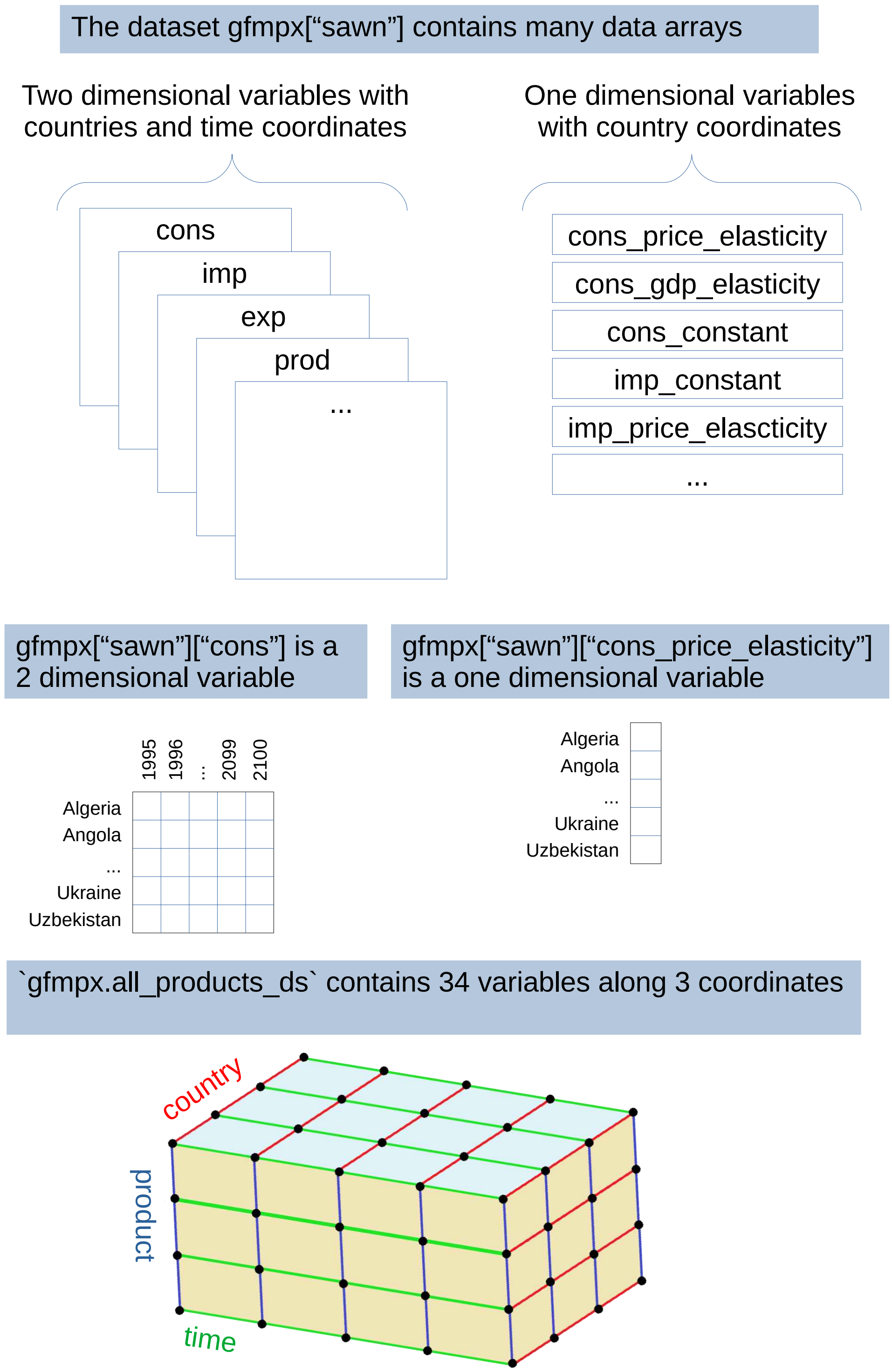

Figure 1: A dataset composed of N dimensional data arrays

Input, output

Scenario configuration files stored as yaml in the `cobwood_data/scenario` directory enable users to define different input parameters and input data files for each modeling scenario. By tracking all assumptions in a single location, these configuration files ensure simulation reproducibility. Cobwood can load data from any tabular source that pandas supports. For instance, the GFPMx data is stored inside csv files which the `GFPMXData.convert_sheets_to_dataset` method then transforms into an Xarray data structure. Other methods make it possible to load forest products market data from the FAOSTAT API and transform them into xarray datasets.

The `write_datasets_to_netcdf` function combines the 2D datasets of many products into one larger 3D dataset, by adding a third coordinate called "`product`" before saving the model output datasets to NetCDF files. These files include metadata labels for units. While not commonly used in economics, NetCDF is a widely accepted format in earth systems modelling, making it ideal for integrated modelling systems.

Model run

The following code instantiates a GFPMx model object from a scenario yaml file. The `rerun=True` argument erases previous model runs, while `compare=True` compares output with the reference implementation of GFPMx.

```
from cobwood.gfpmx import GFPMX
gfpmxb2021 = GFPMX(scenario="base_2021", rerun=True)
gfpmxb2021.run(compare=True, strict=False)
```

The model output data is saved inside the model's `output_dir` directory. When re-using the model later, specify the argument `rerun="False"` (default) to load the output data without the need to run the model.

Visualisation

The following Python code draws a faceted plot of industrial roundwood consumption, import, export, production and price with one line per country.

```
gfpmxb2021.facet_plot_by_var("indround", countries=["Canada", "France", "Japan"])
```

The Journal of Open Source Software

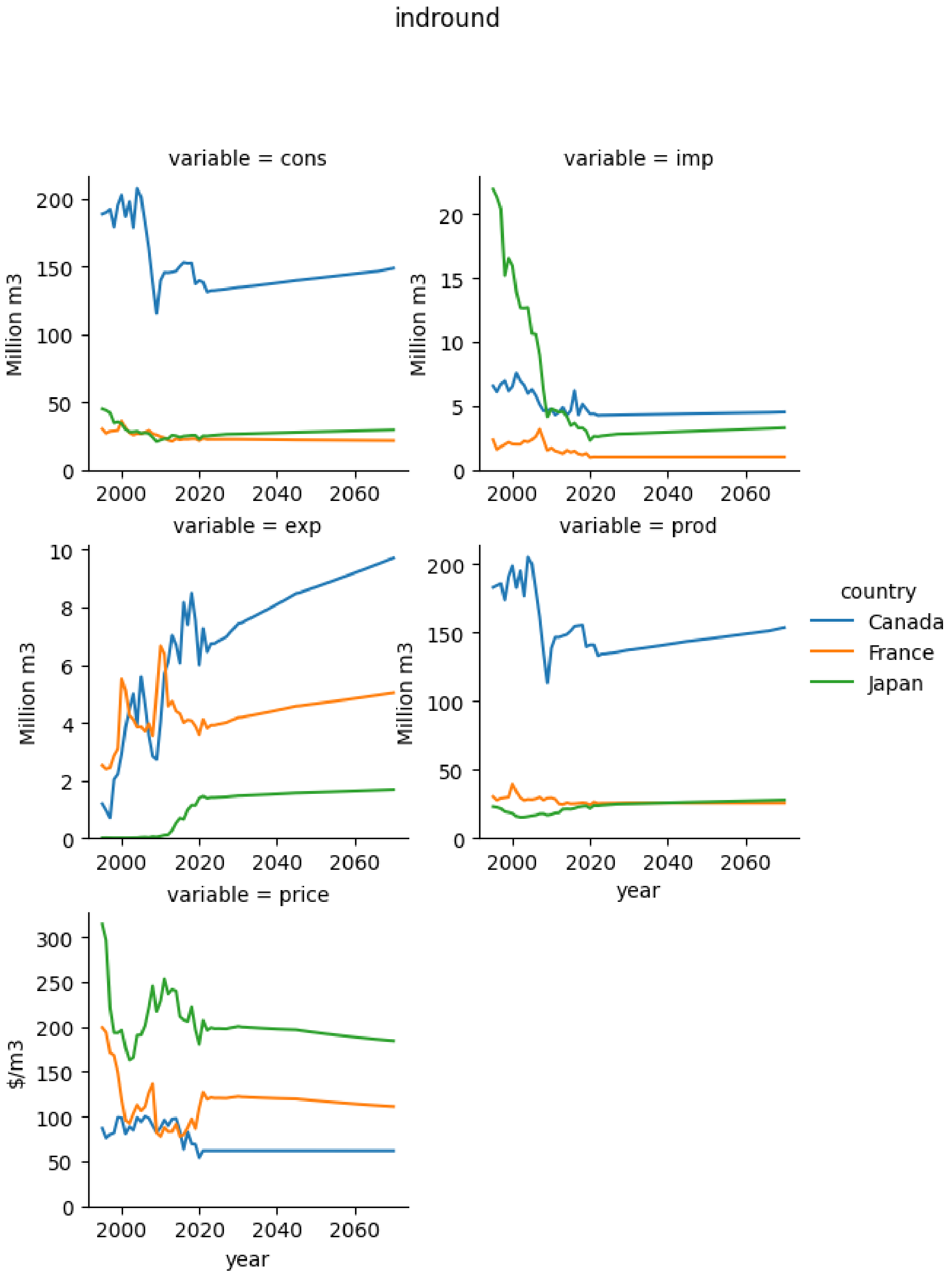

Figure 2: Industrial roundwood consumption, import, export, production and prices by country

The following code draws a heat map of net trade for the 20 countries by absolute net trade, for all products.

```
gfpmxb2021.trade_balance_heatmap(year=2021, top_n=20)
```

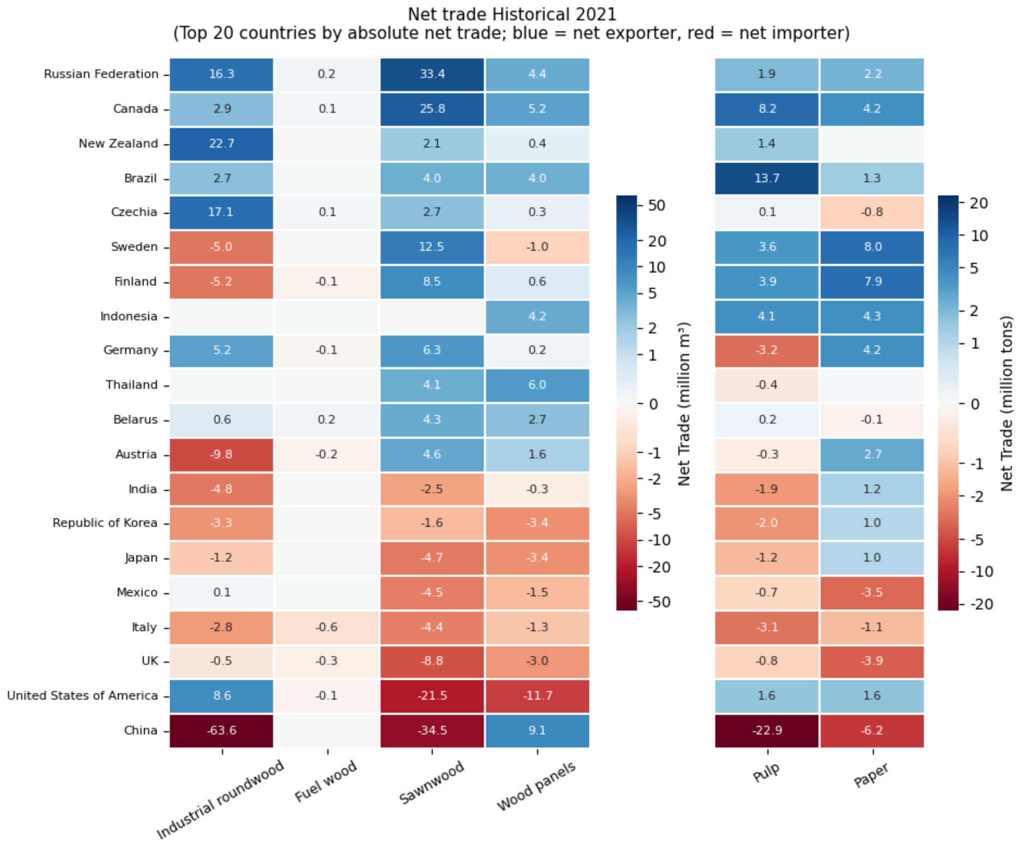

Figure 3: Net trade of forest products for major countries

Conclusion

The cobwood package represents macroeconomic forest products market data as N-dimensional labelled data arrays. The data structure incorporates comprehensive metadata and coordinates, improving source code readability and model transparency. Additionally, the scenario configuration file enables comparison of different model implementations across variations of input parameters. Furthermore, model outputs are saved to NetCDF files, which preserve dimensions and metadata. This data structure will be reused to implement many other forest sector models. Ultimately, the goal is to facilitate the integration of forest sector models as components of interdisciplinary modelling tool chains.

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