BoARIO: A Python package implementing the ARIO indirect economic cost model

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Software

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Summary

The impacts of economic shocks (caused by natural or technological disasters for instance) often extend far beyond the cost of their local, direct consequences. Part of these indirect consequences are caused by the propagation of the economic perturbations along supply chains. Understanding the additional impacts and costs stemming from this propagation is key to design efficient risk management policies. The interest is rising for the evaluation of these "indirect risks" in the context of climate change–which leads to an increase in the average risk of weather extremes (Lange et al., 2020), and globalized-just-in-time production processes. Such evaluations rely on dynamic economic models that represent the interactions between multiple regions and sectors. Recent research in the field argues in favor of using more Agent-Based oriented model, associated with an increase in the complexity of the mechanisms represented (Coronese & Luzzati, 2022). However, the assumptions and hypotheses underlying these economic mechanisms vary a lot, and sometimes lack transparency, making it difficult to properly interpret and compare results across models, even more so when the code used is not published or undocumented.

The Adaptive Regional Input-Output model (or ARIO) is an hybrid input-output / agent-based economic model, designed to compute indirect costs consequent to economic shocks. Its first version dates back to 2008 and was originally developed to assess the indirect costs of natural disasters (Hallegatte, 2008). ARIO is now a well-established and a pivotal model in its field, has been used in multiple studies, and has seen several extensions or adaptations (Guan et al., 2020; Hallegatte, 2008, 2013; Hallegatte et al., 2010; Henriet et al., 2012; Jenkins, 2013; E. E. Koks et al., 2015; Ranger et al., 2010; C. Wang et al., 2018; D. Wang et al., 2020; Wu et al., 2011).

In ARIO, the economy is modelled as a set of economic sectors and regions, and we call a specific (region, sector) couple an *industry*. Each industry produces a unique product which is assumed to be the same for all industries of the same sector. Each industry keeps an inventory of inputs it requires for production. Each industry answers a total demand consisting of the final demand (from households, public spendings and private investments) and of the intermediate demand (from other industries). An initial equilibrium state for the economy is built based on a multi-regional input-output table. The model can then describe how the economy, as depicted, responds to a shock (or multiple ones).

`BoARIO` is an open-source Python package implementing the ARIO model. Its core purpose is to help support better accessibility, transparency, replicability and comparability in the field of indirect economic impacts modeling.

Statement of need

Although the ARIO model has been used in multiple studies, and several extensions exists, only a few implementations of the model or similar ones are openly available. We found the following existing implementations:

- A Python implementation of MRIA (Elco E. Koks & Thissen, 2016).
- A Python implementation of Disrupt Supply Chain (Colon et al., 2020).
- A C++ implementation of the Acclimate model (Otto et al., 2017).
- A Matlab implementation of C. Shughrue's model (Shughrue et al., 2020).
- The ARIO models version used in Guan et al. (2020).

We found that none of these implementations offer a comprehensive documentation, and are generally specific to the case study they were used for. The purpose of the `BoARIO` package is to offer a generic, documented, easy to use, easy to extend, and replicability-oriented model for indirect impact assessment.

The `BoARIO` package allows to easily run simulations with the ARIO model, via simple steps:

- Instantiating a model
- Defining one or multiple events
- Creating a simulation instance that will wrap the model and events, allow to run the simulation, and explore the results.

The ARIO model relies on Multi-Regional Input-Output Tables (MRIOTs) to define the initial state of the economy. `BoARIO` was designed to be entirely agnostic of the MRIOT used, thanks to the `pymrio` package (Stadler, 2021). This aspect notably permits full benefit from the increasing availability of such tables (Lenzen et al., 2012; OECD, 2021; Stadler et al., 2018; Thissen et al., 2018).

The package allows for different shocking events to be defined (currently, shocks on production or shocks on both production and demand, by including a demand stemming from the reconstruction effort, the inclusion of shocks on demand only and other types of shock will be added in future versions). As such, different types of case studies can be conducted (at different scope, for multiple or singular events). Users benefit from a precise control on aspects such as the distribution of the impact towards the different sectors and regions, the recovery from the impact, and also from the default modeling choices common in the corresponding literature. The rationale for the detailed configuration of the model is "allowing for, but not require".

Simulations log the evolution of each variable of interest (production, production capacity, intermediate demand, reconstruction demand, etc.) at each step and for each industry, in `pandas DataFrame` objects, allowing in depth descriptions and understanding of the economic responses. The package can be used "live", e.g. in a Jupyter Notebook, as well as in large simulation pipelines, for instance using the `Snakemake` package from Köster & Rahmann (2012)[1].

As such, `BoARIO` is designed to be used by researchers in economics and risk analysis and analysts, and possibly students, either as a theoretical tool to better understand the dynamics associated with the propagation of economic impacts, for more applied-oriented case studies in risk management, or simply as a pedagogical tool to introduce the indirect impact modeling field.

The Python implementation, accompanied by the online documentation (where a more in depth description is available), offers an accessible interface for researchers with limited programming knowledge. It also aims to be modular and extensible to include additional economic mechanisms in future versions. Finally, its API aims at making it interoperable with

[1] Both these uses have already been extensively employed in ongoing studies.

other modeling software: for instance the CLIMADA platform (Siguan et al., 2023) to which BoARIO is in the process of being integrated.

Status

BoARIO is released under the open-source GPL-3.0 license and is currently developed by Samuel Juhel. The core of its development was made over the course of a PhD at CIRED and LMD, under the supervision of Vincent Viguié and Fabio D'Andrea, and funded by ADEME (the French agency for transition).

BoARIO can be installed from PyPi or Conda-Forge using:

```
pip install boario

conda install -c conda-forge boario
```

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