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A Research Framework for Ecological Macroeconomics

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A Research Framework for Ecological Macroeconomics

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Abstract

Ecological macroeconomics has been expanding as a sub-field within ecological economics in the last decade. Applying almost exclusively non-neoclassical, or 'heterodox', macroeconomic theory, ecological macroeconomic models incorporate biophysical stocks and flows. Yet, they are not well-suited to exploring the more transformative agendas proposed within ecological economics writ large. The challenges of doing so are prodigious, but that points to the need for research. With the ultimate goal of informing policy-oriented models, including scenario models, this paper proposes a framework for research along a 'research-to-application pipeline'. It argues the need for a common framework and suggests combining two well-established practices: from macroeconomics, the practice of characterising models by their accounting relationships, behavioural rules, and closures; and, from system dynamics modelling, the adoption of 'confidence-building procedures'. The proposed research-to-application pipeline creates a division of labour over the task of confidence building, with the accounts-behaviour-closure (or 'ABC') approach providing a common language. The paper refers to existing work and explicitly addresses the critical realist critique of model closure.

Keywords: ecological macroeconomics, post-Keynesian, post-growth, degrowth, critical realism
JEL: C54, E11, E12, P41, Q57

1. Introduction

This paper proposes a framework for doing research in ecological macroeconomics, drawing on ideas and practices from both macroeconomics and ecological economics. Ecological macroeconomics has grown rapidly in the past decade as a recognised and active field of study. A Scopus search for the phrase 'ecological macroeconomics' in title, abstract, or keywords returns just 7 publications before 2015 but 65 from 2015 onward. A broader Google Scholar search for the exact phrase in documents returns 164 before 2015 and 1,180 from 2015 onward.

In some sense, the field is not at all new. Arguably, it began in the 18th Century with the Physiocrats, who grounded economics in biophysical processes (Melgar-Melgar and Hall, 2020). More recently, but still well before 2015, Georgescu-Roegen and Daly argued that the key problem with then-prevailing macroeconomic analysis was that

it ignored problems of scale as raised in the 'limits to growth' debate (Nadal, 2011, pp. 22ff). Daly (1992) argued that the main challenge is to determine the economy's optimal scale. Recent work acknowledges the relevance of scale but rather than seeking an optimum and maintaining a singular focus on biophysical limits, it starts from the idea that the economy is a set of institutions embedded in society, which is itself embedded in nature. The entry for 'Ecological Macroeconomics' in the *Elgar Encyclopedia of Post-Keynesian Economics* (Espagne et al., 2023) summarises the field as follows:

> Ecological macroeconomics is a relatively new strand of literature aiming to integrate the insights from ecological economics with those of different streams of heterodox macroeconomics. Ecological macroeconomics is an approach to macroeconomics that seeks to explicitly account for the economic system as a sub-system of the planet's biophysical systems. The field describes and analyses how systems of finance, production and distribution both depend upon, and direct the transformation of materials and energy.

Much of the published work fits this description, with a preponderance of publications focused on energy use and greenhouse gas emissions. Yet, despite its rapid growth, contemporary ecological macroeconomics has arguably not lived up to its name. Espagne et al. (2023) critique ecological macroeconomists for 'tweaking' existing policies rather than studying the transformative changes proposed by ecological economists. The tweaked policies typically assume growth as a goal, consistent with post-Keynesian and other heterodox economic traditions but in contrast to the tradition of Georgescu-Roegen and Daly.

Recent calls for 'post-growth' models are better aligned with the ecological economics tradition. They de-emphasise economic growth as a goal and emphasise human well-being and social equity, as well as environmental sustainability. However, Van Eynde et al. (2026) found tensions between what a survey of modellers – primarily members of large modelling teams – identified as required for post-growth modelling and what the post-growth literature itself recommends. Identified gaps include the unsophisticated treatment of environmental feedback mechanisms and lack of non-market provisioning. Somewhat surprisingly, they found that the models could also improve their treatment of finance, something that post-Keynesian ecological macroeconomists prioritise (Espagne et al., 2023) but that has apparently not been incorporated into applied post-growth models. Moreover, Van Eynde et al. (2026) found that modellers who do treat finance do not question its role in the currently prevailing political economy characterised by financialised capitalism.

The state of ecological macroeconomic theory and modelling thus appears unsatisfactory. In response, this paper proposes a research framework aimed at improving the state of both theory and applied modelling within ecological macroeconomics. It envisages a 'research-to-application pipeline' in which fundamental work on representing processes both informs macroeconomic theory and produces model components, or sub-models, that can be incorporated (with modification) into large integrated models aimed at policy analysis or scenario construction. Informing macroeconomic the-

ory is important because, per Nadal (2011, chaps. 2 & 7), macroeconomic theory *is* macroeconomic policy, in that theoretical frameworks guide policymaking. From personal experience, this author would argue that theory informs policy through two main mechanisms: first, macroeconomic theory determines what policies are 'in bounds' and 'out of bounds' for consideration, before any formal analysis takes place; and, second, the models that are applied must conform to accepted theoretical frameworks. The same mechanisms arguably constrain the breadth of futures that can be represented in scenario models (Lauer et al., 2024; Slameršak et al., 2026).

The production of sub-models is likewise important. In the context of system dynamics modeling, Forrester and Senge (1980) argued for a cumulative process of 'confidence building'. Measures to build confidence include *structure verification* ('the model structure must not contradict knowledge about the structure of the real system'), *parameter verification* ('comparing model parameters to knowledge of the real system to determine if parameters correspond conceptually and numerically to real life'), *extreme conditions testing* (ensuring the model behaves reasonably in rarely-visited parts of its domain), checking for *boundary adequacy* ('developing a convincing hypothesis relating proposed model structure to a particular issue addressed by a model'), *behaviour reproduction* and *behaviour prediction*, and so on (see Sterman, 2000, chap. 21 for a more comprehensive and updated list).[1] The confidence-building activities for ecological macroeconomics go beyond this list, because the 'real system' may differ substantially from currently prevailing systems. Sub-models can still be grounded by small-scale exemplars, historical examples, and knowledge of human behaviour, but those investigations take time and effort. From the point of view of applied modelling, basic research focused on model components facilitates a division of labour over the essential but arduous process of confidence building.

This paper argues that the links between basic research and application can be facilitated by structuring sub-models using a combination of *accounts*, *behaviours*, and *closures* – what the author calls the 'ABC approach' to macroeconomic modelling. It is a widely used approach; as noted by Taylor (2004, chap. 1),

> [M]acroeconomics is framed by social accounting and social relations. The social accounts form a skeleton, and social relations change the skeleton's position over real, historical time. Specifying just which relations drive the motions is not a trivial task... But the objects that move – the observable phenomena in macro – are mostly the numbers making up the national income and product accounts (NIPA), the flow of funds (FOF) accounts, and allied systems.

He then adds that model closure involves 'selection among various behavioural restrictions to append to [social accounting matrix (SAM)] balances to give an algebraically complete model.' Similarly, Cohen (2013, chap. 2) argues that economy-wide policy

[1]Note that dynamic stochastic general equilibrium (DSGE) models do not satisfy these criteria. We emphasise that the listed criteria are standard in system dynamics modelling.

models must be based on at least four accounting relationships that reflect supply-demand balances: inputs to production; goods and services; financial markets; and exchanges with the rest of the world. Closure is then assured by specifying 'adjustor' variables. Accounts and closures alone can sometimes suffice for static models, while behavioural equations are needed for dynamic models (Cohen, 2013, chap. 6). Ecological macroeconomics introduces further accounts, particularly biophysical accounts, with associated behavioural rules and possible closures (recent examples include Cieplinski et al., 2021; Sebastian Espinoza et al., 2022; Jacques et al., 2023; Jackson and Jackson, 2025).

The proposed approach aligns closely to that followed by structuralist development economists (Taylor, 1990; Ocampo et al., 2009; Gibson, 2010; Fischer, 2026). This is an appropriate connection because ecological economists point to structural barriers to transformation and, just as in development economics, they seek to understand the consequences of large-scale structural change. The structuralist literature stresses the need to take context into account, arguing that model closures must be chosen with prevailing economic structures in mind (Fischer, 2026).

Using the ABC approach as a frame, and with confidence building as a goal, sub-models should contain relevant and grounded accounting and behavioural relationships. They can then be intensively investigated across multiple closures. If successful, this should increase confidence in using them as components within integrated ecological macroeconomic models. Such a practice would address a critique from Van Eynde et al. (2026) that innovation within the context of existing large models impedes understanding of the innovations and their interactions with other model components. They argue that, '[T]he economic theory upon which a particular model is based can significantly affect the outcomes of modelled transition scenarios... Due to the relatively large size of most models used in post-growth scenario research, it is challenging to understand how model outcomes are affected by embedded assumptions.' If sub-models are submitted for peer review outside of large models – whether by modelling teams or others – they can be critiqued and refined, and alternative approaches to modelling a particular process can be advanced and debated.

The proposed research framework is in fact how most theory develops within post-Keynesian, Sraffian, classical, and related macroeconomics. However, it appears not to be the way that ecological macroeconomics is currently developing. There are several reviews that compare complete models across a selected number of dimensions (e.g., Fevereiro et al., 2025; Hardt and O'Neill, 2017; Lauer et al., 2025; Van Eynde et al., 2024). This is welcome, but it restricts attention to complete models. This paper argues that more stress should be placed on key *processes* and associated *system components* that have been identified as important to a robust ecological macroeconomics. The identified processes may already be implemented to some degree within existing models, but each model offers at most one approach, and the comparative reviews do not focus on competing implementations. In contrast, the broader literature may reflect a debate over alternatives. So, for example, Van Eynde et al. (2026) identified a lack of non-market provisioning as a gap in post-growth modelling. Meanwhile, there is an active

research programme on representing non-market care provisioning in post-Keynesian macroeconomic models. Blecker and Braunstein (2022) introduce a special issue on the topic featuring diverse modelling approaches, and contributions are ongoing (Setterfield, 2026). Particularly where gaps have been identified, but even on seemingly settled topics, the field of ecological macroeconomics should engage with ongoing research over how to best represent relevant processes.

Just what the key processes and system components might be is a separate question, and answers to that question constitute research agendas. Farley and Kish (2021) propose a 30-year agenda for ecological economics (not just ecological *macro*economics) that would research 'uncertainty, co-evolution, social dilemmas, the normative and performative nature of [ecological economics], methodological pluralism and the need for radical change.' As items in an agenda for ecological macroeconomics specifically, authors have proposed, among others: alternative institutional and governance arrangements (Espagne et al., 2023); links from income and wealth inequality to macroeconomic outcomes as well as feedbacks arising from changes to working time (Hardt and O'Neill, 2017); social support, political voice, and access to housing and mobility (Van Eynde et al., 2024); and 'conviviality' and firm ownership (Kemp-Benedict, 2025). But pursuing a research agenda requires a framework to facilitate comparison and incorporation into integrated models. This paper aims to provide such a framework.

In the remainder of this paper, Section 2 describes the 'ABC' approach in more detail, together with a discussion of 'stylised facts'. Section 3 offers a broader discussion, including the possible structure of a 'research-to-application pipeline'. Section 4 concludes.

2. The 'ABC' approach

Macroeconomic modelling has some well-established procedures, although they are implemented differently by different modellers and sometimes challenged on methodological grounds. As noted in the Introduction, we propose to view models in terms of *accounts*, *'behavioural' rules*, and *closures*. This will be termed the 'ABC' approach. The word 'behavioural' is put in quotation marks because, while behavioural rules are meant to arise from the actual behaviours of economic actors, they express relationships between economic aggregates and may not be simply related to any single individual's actions; as emphasised by Shaikh (2016, chap. 3), diverse and even contradictory microeconomic models can give rise to the same aggregate relationship. Each of these elements – accounts, behavioural rules, and closures – is briefly explained in this section, together with some commentary on their relevance to ecological macroeconomics.

2.1. Accounts

Accounts are a powerful tool in macroeconomic analysis. Part of their power comes from their comparative acceptability and lack of controversy. The same basic accounts – mainly the national accounts as defined by the United Nations – are used by economists working in most macroeconomic traditions.

As an example of how they can be applied, the equation of leakages (saving, imports, and taxes) with injections (investment, exports, and government expenditure) gives rise to the rule that the private, public, and external balances must sum to zero. Thus, a rise in imports – for example, to obtain capital goods not manufactured in the country – must be accompanied by either a rise in government expenditure, an increase in net capital inflow, or a combination of the two. Precisely *how* that happens is dealt with through behavioural rules and closures, but the accounts alone constrain the policy space. Biophysical accounts in ecological economics play a similar role, as in the concept of 'planetary boundaries' (Richardson et al., 2023).

National economic accounts collected in accordance with the United Nations System of National Accounts (SNA) provides the data for most macroeconomic analysis, but they are incomplete from an ecological economics perspective. A new 2025 version of the SNA has recently been completed and released in pre-edit form.[2] The document specifies what lies inside and outside the 'production boundary'. For example, the implicit flow value of capital – for example, the implied rental expense of owner-occupied housing – lies within the boundary, while the value of unpaid household service work does not, thereby privileging a particular notion of 'value'. More broadly, the aspects of material well-being included in the integrated framework of the national accounts are (from Fig. 34.1 of the pre-edit document): income; final consumption; labour; and household distributions of income, consumption, and wealth. Aspects of material well-being lying outside the framework but covered in extended accounts include: unpaid household service work; ecosystem services; health care activity; and education and training activity. The document recognises that other, non-material, aspects of well-being are entirely excluded, including: subjective well-being; governance; social cohesion; health outcomes; crime and justice outcomes; leisure; and capabilities and freedoms. Notably, the items *not* included within the boundary are highly relevant to the 30-year agenda for ecological economics proposed by Farley and Kish (2021).

A specific accounting framework – stock-flow consistent (SFC) modelling (Godley and Lavoie, 2016) – is widely accepted in the ecological macroeconomics literature (Jackson and Victor, 2020; Carnevali et al., 2023), sometimes as an expanded set of 'stock-flow-fund' accounts (Dafermos et al., 2017; Barth and Richters, 2019). SFC models are consistent with the accounting principles behind the SNA but take a different form. They use 'quadruple entry' accounting in which transactions, such as between a seller and a buyer, are combined with matched income and use of funds for aggregate entities, such as households. Changing any one entry requires corresponding changes to at least three other entries, which limits the number of independent variables. This makes it possible to add sectors and transactions without too rapid a decline in tractability. SFC models are particularly useful for analysing financial flows, but are arguably now considered best practice for ecological macroeconomic models of any kind.

Additional, non-monetary, accounts are also relevant to ecological economists. Faye

[2]Available at https://unstats.un.org/unsd/nationalaccount/sna2025.asp.

Duchin (2013) has long combined monetary and non-monetary accounts in environmentally-extended input-output models to address problems in ecological economics. This is now an active area of empirically-grounded work, with recent papers including Jaccard et al. (2021) and Carneiro et al. (2026). Zhang et al. (2026) combine a multi-regional input-output (MRIO) model with social indicators to analyse inequality across supply chains from a sustainability perspective. Dafermos et al. (2017) and D'Alessandro et al. (2020) produced models incorporating linked monetary and non-monetary accounts, while Okuma (2017) explored scenarios for Japan using an environmentally-extended post-Keynesian model. Non-monetary accounts of potential interest for ecological macroeconomics include but are not limited to energy balances, material flow accounts, nutrient balances, water budgets, land-use balances, time-use accounts, and demographic accounts.

2.2. Behavioural rules

Behavioural rules specify how variables in a model relate to one another. With respect to the accounts, they determine the sizes of the flows and therefore changes in stocks. For example, while accounting relationships ensure that saving must equal investment in a closed economy with no government sector or working capital, the question then arises how saving and investment are determined. The 'neoclassical synthesis' IS-LM model relies on market clearing through flexible prices and emphasises the role of the interest rate, assuming that higher rates encourage households to save but discourage firms from borrowing. Solow-type models, as well as dynamic computable general equilibrium (CGE)[3] models, typically build in a 'loanable funds' assumption in which saving is determined exogenously (e.g., through a fixed saving propensity) while investment accommodates to saving, again through price adjustment. Post-Keynesian models typically assume fixed or interest rate-inelastic marginal saving propensities together with an investment function that depends mainly on profits and capacity utilisation and only secondarily (if at all) on interest rates. In post-Keynesian theory, interest rates operate mainly through a distribution channel (Seccareccia and Lavoie, 2016).

In equilibrium or comparative-statics analyses, behavioural rules constrain outcomes. For example, a neoclassical price equilibrium model would solve for prices (the closure) given demand and supply price schedules (the behavioural rules) and accounting relationships. In Kaleckian post-Keynesian models, capacity utilisation (closure) is determined given the saving and investment functions (behaviour) and accounting relationships. In Kaldorian post-Keynesian models, the profit rate (closure) is determined

[3]While 'dynamic' and 'general equilibrium' might seem at odds, dynamic CGE models essentially model a sequence of price equilibria. The capital stock changes between time steps, and saving from one period constrains investment in the subsequent period. Dynamic CGE models are process-based and are therefore entirely different from DSGE models, which link sequential equilibria within an intertemporal optimising framework. Most applied CGE models are neoclassical but that is not required, and structuralist CGEs with post-Keynesian closures also exist (Taylor, 1990).

given the saving rate of rentiers (behaviour) and accounting relationships. Similar observations apply to classical and Sraffian models, in which a conventional wage, combined with a uniform rate of profit, determines long-period or 'normal' prices.[4] For this reason, equilibrium and comparative-statics exercises are effective methods for testing and exploring proposed behavioural rules. They are part of the confidence-building procedures for demonstrating the usefulness of models and sub-models. What is more, they can be used for rapid, 'back of the envelope', policy analysis. Nevertheless, in practice, most ecological macroeconomic models for policy and scenario analysis are integrated dynamic models.

In dynamic models, behavioural rules say how state variables change over time as a function of the state. To take the saving-investment example from above, some dynamic post-Keynesian models assume that the rate of change in capacity utilisation is proportional to (the negative of) the gap between saving and investment, while saving and investment functions depend on capacity utilisation (Lavoie, 2022, pp. 405ff). The assumption can be motivated by the observation that the gap between saving and investment is the change in inventories; the rule abstracts from inventories but implicitly assumes that firms reduce their capacity utilisation when inventories rise. The dynamic is stabilising if the so-called 'Keynesian stability condition' holds, in which saving responds more strongly to a change in capacity utilisation than does investment.

Integrated dynamic models combine numerous interacting dynamic processes, which can be either linear or non-linear, and which can result in any of the classic patterns identified by systems dynamics modellers (Sterman, 2000, pp. 108ff): exponential growth (or decay); goal seeking; S-shaped growth; oscillation; growth with overshoot; and overshoot and collapse. Non-linear models can result in more complex behaviours, such as limit cycles or even chaotic attractors (Sternberg, 2010).

As these comments illustrate, behavioural assumptions can dramatically impact model results. Moreover, behavioural assumptions (as well as closures) largely distinguish different economic traditions. For ecological macroeconomists, post-Keynesian and other heterodox macroeconomic traditions offer a wealth of potential behavioural rules. However, as a research programme, ecological macroeconomics must go beyond them, because ecological economists argue that societies must substantially transform modes of provisioning and associated social and economic institutions (Vogel et al., 2021; Bärnthaler and Gough, 2023; Kreinin et al., 2024). Such a shift would alter the individual-level behaviours that underpin aggregate 'behavioural' rules. The need for new behavioural rules is the main reason to seek a division of labour in ecological macroeconomics between research into specific processes and integrated models that combine a variety of sub-models for policy and scenario analysis.

[4]Post-Keynesian theory is covered in several excellent textbooks, including Hein (2014) and Lavoie (2022). Classical models are covered by Foley et al. (2019) and long-period position analysis is discussed in Kurz and Salvadori (1995). Blecker and Setterfield (2019) contrast several heterodox traditions. There is no textbook for Sraffian theory, but there are several good monographs and numerous papers.

2.3. Closure

Fundamentally, model closure is a mathematical requirement: a closure ensures that all endogenous model variables are determined within the model once values (or time trajectories) for exogenous model variables have been specified. Without a closure, a model cannot be solved (for pen-and-paper analytical models) or executed (for numerical simulation models).

Closure is often identified with causality. Taylor (2004, chap. 5) noted that he and Lysy in 1979 'popularized the not overly felicitous word "closure" as a shorthand description of a model's causal structure.' Cohen (2013, chap. 2) also presents closures in terms of causal structure. However, as discussed in the Introduction, closures need not reflect underlying causal processes. For example, neoclassical models assume market-clearing prices, so prices follow from other assumptions. But the actual causal processes by which prices are set are abstracted away (a topic explored extensively but inconclusively by Fisher, 1983). In terms of the closure, preferences 'cause' prices, but it would perhaps be better to say that preferences *determine* prices in the model, while the underlying causal processes are implicit. The same is true for dynamic models in which rapidly-equilibrating processes are treated as though they are instantaneous. In the model, slower-moving variables appear to 'cause' fast-moving ones, but in fact the rapidly-adjusting variables are changing through unspecified causal processes within an environment determined by the slow-moving variables.

When used to describe models, both 'behaviour' and 'causality' should therefore be seen as metaphors rather than literal descriptions. There is a deeper reality underlying the model in which actual behaviours may contribute to outcomes and therefore be said to – at least partially – cause them. This layered understanding aligns with a critical realist approach to economics, which brings us to the critical realist critique of model closure. Critical realists note that the world is open, not closed (Lawson, 2003), so invoking a closure is at least ontologically questionable, if not incoherent. As Setterfield (2003) points out, in open systems, external factors may influence outcomes in a non-systematic fashion (lack of extrinsic closure) and, conversely, causes may not always have the same effects (lack of intrinsic closure). It then follows that open systems are not characterised by the kind of event regularities observed in effectively closed systems; for example, in laboratory settings.

While the author is not expert in critical realism, some attempt at a response to the critique will be made here. The response makes two claims: the proposed research framework is essentially retroductive in its search for knowledge; and model closure in applied settings is a practice rooted in human decision-making.

Regarding the first claim, as noted in Subsection 2.2, the main purpose of the framework is to elaborate new behavioural rules based on the broader ecological economics literature – as well as, increasingly, post-Keynesian and other literatures as they take up ecological economic themes. Those behavioural rules apply at an aggregate level, but must be ontologically grounded in social and ecological processes. From Lawson (2003, p. 80),

> To pursue causal explanation as interpreted here, we require a mode of inference that takes us behind the surface phenomenon to its causes, or more generally from phenomena lying at one level to causes often lying at a different deeper one. This is *retroduction*.

That is, broadly, the mode of inquiry proposed in this paper. Retroduction is a highly demanding practice that cannot be pursued for every important process by an individual modelling team. That holds particularly for any *novel* processes with at best niche historical analogues. Repeating the point made in Subsection 2.2, it is for this reason that there is a need for a division of labour between those deeply researching specific processes and modelling teams that make use of the fruits of that research – although, to be sure, some of the researchers will be members of modelling teams.

A methodological feature of the proposed framework that partially answers the critical realist critique is what Setterfield (2003) calls the 'open system *ceteris paribus*' (OSCP) approach. The OSCP approach relies on deploying stylised facts (discussed in Subsection 2.4) together with a process of 'locking up without ignoring' features of reality in order to focus attention on the process under study. Locking up without ignoring is realised through *conditional* closures imposed for the purpose of gaining insight. Applying multiple closures to the same set of accounts and behavioural rules – a practice advocated by Taylor (1990, 2004) and demonstrated by Cohen (2013) – is a useful way to explore and test the implications of the accounts and behaviours. It is both a retrodictive research practice and a confidence-building measure.

The second claim, that model closure is an extension of normal human decision-making practices, derives from the ontological claim in the post-Keynesian literature that all decisions are undertaken under conditions of fundamental uncertainty. There is also, of course, epistemic uncertainty, characterised by poor and incomplete data. However, fundamental uncertainty is irreducible. In a famous passage, Keynes (1937) wrote

> By "uncertain" knowledge, let me explain, I do not mean merely to distinguish what is known for certain from what is only probable. The game of roulette is not subject, in this sense, to uncertainty; nor is the prospect of a Victory bond being drawn. Or, again, the expectation of life is only slightly uncertain. Even the weather is only moderately uncertain. The sense in which I am using the term is that in which the prospect of a European war is uncertain, or the price of copper and the rate of interest twenty years hence, or the obsolescence of a new invention, or the position of private wealth owners in the social system in 1970. About these matters there is no scientific basis on which to form any calculable probability whatever. We simply do not know. Nevertheless, the necessity for action and for decision compels us as practical men to do our best to overlook this awkward fact and to behave exactly as we should if we had behind us a good Benthamite calculation of a series of prospective advantages and disadvantages, each multiplied by its appropriate probability, waiting to be summed.

While Keynes focused on probability, a similar observation applies to model closure. In an interpretation of Tony Lawson (1997), Setterfield (2003, p. 96) notes that 'anxiety in the face of systemic openness is seen to result in the deliberate creation of synthetic closures by individuals in the form of rules, norms, conventions, etc.' In the same vein, Beckert (2013) argues that economic decision-makers construct – and promote – 'fictional expectations' to guide action. In other words, the fictions have a causal force in the economy, which makes them a feature of reality, according to Bhaskar (2011). The fictional expectations resolve the irreducible openness of the world by telling stories about plausible futures, what Patomäki (2006) calls 'artificial closures'. Beckert argues that the force for action that the stories have is essentially emotional, echoing insights from neuroscience that suggest the feeling of certainty is also emotional (Burton, 2009). The satisfaction of being certain helps to close off endless chains of reasoning in an open world and come to a decision. In short, human decision-making is ultimately an irrational, emotional, but necessary act of closure.

The fictional expectations and synthetic (or artificial, or temporary, or conditional) closures that people use in routine decision-making have been formalised in such practices as technology foresight studies (Miles, 2010), scenario planning (Amer et al., 2013), and multi-criteria analysis (Montibeller and Franco, 2010). An explicit goal of technology forecasting and multi-criteria analysis is to reach closure on a decision. Scenario analysis may also support a decision but can also be used for purely exploratory purposes. Regardless, each considered scenario features a conditional closure.

When used for policy or scenario analysis, macroeconomic model closure serves an analogous purpose to that of closure in human decision-making: it allows for conclusive results within a conditional, fictional, structure. Uncertainty is captured by exploring multiple possible futures through alternative closures. The lesson for model design is that models must be able to represent current economic structures and processes as well as the range of policy options and potential futures identified as needing analysis.

2.4. The role of stylised facts

Economics as a field sometimes relies on so-called 'stylised facts'. At any moment, the set of recognised stylised facts can be used to constrain or evaluate proposed models. The concept of stylised facts was introduced by Kaldor (1961). He argued (op. cit., p. 178),

> Since facts, as recorded by statisticians, are always subject to numerous snags and qualifications, and for that reason are incapable of being accurately summarized, the theorist, in my view, should be free to start off with a 'stylized' view of the facts – i.e. concentrate on broad tendencies, ignoring individual detail, and proceed on the 'as if ' method, i.e. construct a hypothesis that could account for these 'stylized' facts, without necessarily committing himself on the historical accuracy, or sufficiency, of the facts or tendencies thus summarized.

Because stylised facts are hypotheses, they serve as reference points for models used as explanatory tools. An example with which the author has worked is the classical-evolutionary theory of technological change first proposed by Duménil and Lévy (1995, 2010). In that theory, a random search for new technologies, subject to the requirement that implemented technologies must raise firms' profit rates, immediately implies the stylised fact of technical change biased towards saving labour. In contrast, the leading neoclassical model generates labour-saving technological change only under extreme assumptions and offers no *a priori* reason why labour-saving, rather than capital-saving, technological change should emerge (Acemoglu, 2002, p. 804). When coupled with realistic (but not unique) price- and wage-setting behavioural rules, Duménil and Lévy's theory can produce an equilibrium position characterised by Kaldor's stylised facts of a tendency towards Harrod-neutral technological change and constant cost shares (Kemp-Benedict, 2019). Kaldor's proposed stylised facts broke down in the 1970s, so they cannot hold true in all cases, an outcome explained by Kemp-Benedict (2022) with the classical-evolutionary model as resulting from abrupt changes in energy cost shares. The correspondence between model results and stylised facts – as a tendency, not a rule – increases confidence in its application.

Another way to use stylised facts, one that is often adopted in post-Keynesian theory, is to impose them in order to close models. Sometimes an assumed stylised fact is not even specified as part of the closure, because alternatives are not entertained. For example, most post-Keynesian models, whether Kaleckian or Kaldorian, assume constant capital productivity. This is usually introduced as a stand-alone assumption, perhaps with an appeal to Kaldor but no reference to dynamics. If in fact a tendency towards constant capital productivity results from economic dynamics that are not explicit in the model, then as noted above, closing a model by imposing constant capital productivity is non-causal because the causal factors are not present in the model. Instead, the assumption abstracts from the underlying dynamics. As part of a closure, it imposes the outcome of unspecified dynamics as a constraint on the model's behavioural rules.

Stylised facts allow an analytic separation between equilibrium-seeking dynamics and other dynamics. This is a valid procedure as long as the equilibrium position of the implicit dynamics is independent of the explicit model assumptions and deviations are small compared to the model's characteristic scale – otherwise, the approximation may rule out important path-dependent behaviour. When the approximation holds, equilibrium-seeking dynamics can be abstracted away. A more general procedure is to separate dynamics by time scale (Haken, 1993). Fast dynamics can be integrated out and slow dynamics treated parametrically, with only intermediate dynamics explicitly represented. As noted above, while causal processes drive both fast and slow dynamics, those processes are not present in the model, so closing the model by imposing the trajectories arising from the integrated fast dynamics and the parameters that characterise the slow dynamics does not reflect the true underlying causal structure.

Adopting stylised facts and analytically separating temporal scales are standard in macroeconomic modelling. However, conventional stylised facts and time scale as-

sumptions may not carry over to ecological macroeconomic models. That is because ecological economics assumes the economy – and the society in which it is embedded – is undergoing substantial structural and behavioural change. This is a profound challenge to developing ecological macroeconomic models, one that motivates the research framework proposed in this paper. There is a need for new stylised facts. A key example from ecological economics is the observed absence of sustained absolute decoupling of resource use from GDP and insufficiently rapid decoupling of greenhouse gas emissions (Haberl et al., 2020). This observation, combined with the fact that we are exceeding 'planetary boundaries' (Richardson et al., 2023), leads to the degrowth hypothesis that environmental sustainability can only be achieved by reducing economic output (Kallis et al., 2018). Particularly because we have failed to meet human needs despite excessive environmental impacts (Fanning and Raworth, 2025), the goal for economic analysis is to ensure human well-being within a shrinking and stabilising economy (Kallis et al., 2012). In this case, the stylised fact of no decoupling is imposed as a model constraint, much as post-Keynesian models often impose Kaldor's stylised fact of a constant capital productivity. Alternatively, it can be seen as an historical fact to explain – why has absolute decoupling not been observed in the past? – but not necessarily an unalterable feature of future economies – what might change so that absolute decoupling could occur in the future? Kemp-Benedict (2017) is an example of the latter approach.

3. Discussion

Any single individual may be a researcher in the morning and a practitioner in the afternoon. Others may choose to specialise. Regardless, it is useful to separate the tasks involved in a research-to-application pipeline for ecological macroeconomics. The attraction of such a pipeline to both academic researchers and applied modellers is hopefully clear: it signals to researchers the challenging tasks that are salient for applied work; and it informs modelling teams about the degree of support for the model components that they assemble. While the 'pipeline' image is linear, the relationship between actors along the pipeline is dialogic, with insights from research informing policy goals, while bottlenecks in applied policy analysis point towards gaps in basic knowledge. The communication can happen in practice through collaboration, as well as publications (including special issues), conference sessions, and workshops convened for the purpose.

For a research-to-application pipeline to work, contributors must share a reference framework. This paper proposes the accounts-behaviour-closure, or 'ABC', structure for macroeconomic models combined with the notion of confidence-building procedures from system dynamics. It argues that this approach is broadly consistent with at least some strands of thought in critical realism. As ecological economics identifies accounts, behavioural rules, and closures that go beyond those of conventional macroeconomics, the task for research is to integrate the insights from ecological economics writ large into ecological *macro*economics. Arguably, this integration has not yet occurred (Espagne et al., 2023).

For some topics, the empirical evidence is not yet ready to support modelling efforts. In that case, the entry point to the pipeline is basic empirical research. But exploratory models can still be constructed based on the imperfect information available. They can serve as a starting point for future modelling efforts and as a signal that empirical studies are lacking. Those models can be structured as sub-models containing accounts and behavioural rules (or 'AB' sub-models) that are then embedded into small but complete models to be tested against a variety of different closures. Investigations might include: equilibrium analysis, comparative statics, stability analysis, pattern replication, and extreme conditions testing. Sub-models can be proposed and refined, both by comparing and contrasting competing approaches to modelling relevant processes, and through confrontation with new empirical evidence as it accumulates.

A modelling team might incorporate a sub-model at any stage, depending on need, from exploratory models up to well-tested models grounded in a substantial evidence base. However, in the interest of confidence-building it is best if sub-models are adopted when they are comparatively mature. Ideally, modelling teams would be aware of research efforts at the early stages of the pipeline and collaborate with some research teams. A normal progression might be: 1) a single early paper that identifies the research gap and offers an initial modelling approach based on available data; 2) further empirical work to refine (and perhaps invalidate) the initial proposed model, in tandem with alternative candidate models; 3) an increasingly mature, documented, and empirically grounded set of alternatives; 4) adoption of one or more of the models on offer by one or more modelling team.

4. Conclusion

Ecological macroeconomics is a fairly new but rapidly-growing field. It draws largely on post-Keynesian macroeconomic theory and inherits some post-Keynesian policy orientations (Espagne et al., 2023), including acceptance of growth and full employment as goals. But ecological economics offers robust critiques of growth, questions the nature of employment, and suggests a radically different policy agenda of remaining within planetary boundaries while providing for human well-being (Kallis et al., 2012; Fanning and Raworth, 2025). A truly ecological macroeconomics should embrace the task of analysing substantial transformation.

The prospect is daunting, but it provides opportunities for researchers to deeply explore challenging topics. Their efforts will be worthwhile if the fruits of their research ultimately influence practice. To make that more likely, this paper proposes a 'research-to-application pipeline' featuring active collaboration, dialogue, and debate. Research would focus on the most challenging topics within ecological macroeconomics. To facilitate uptake, this paper recommends a shared terminology in terms of accounts, behaviours, and closures – the 'ABC' approach – and a shared set of confidence-building procedures. The research pipeline could then propose 'AB' sub-models with sets of accounts and behavioural rules that can be incorporated into larger models that are then conditionally closed for the purpose of policy analysis or scenario development.

For this to happen, agendas for ecological macroeconomics should identify relevant processes and stylised facts to guide research. Concrete examples offered in the paper include non-market care provisioning (Blecker and Braunstein, 2022) and the stylised fact of no sustained absolute decoupling (Haberl et al., 2020). As noted in the paper, there is no shortage of items to add to an agenda. Were researchers to pursue these challenging topics in dialogue with practitioners, it could facilitate a division of labour over the time-consuming task of confidence-building and raise the ambition of ecological macroeconomics as a field.

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