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Analysis

Transitioning to a sustainable economy: A preliminary degrowth macroeconomic model

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ABSTRACT

The degrowth literature argues that growth in real monetary terms is unsustainable and rejects appeals to decoupling. But it assumes the continued availability of advanced materials and technology. This paper argues that much of the degrowth literature implicitly or explicitly requires an industrial "core." The paper introduces a stylized three-sector model with a formal convivial economy that predominates in everyday life, together with an industrial core and informal household convivial production. Drawing on prior work by post-Keynesian economists, which showed that positive net profit for the economy as a whole is compatible with a steady-state economy if there is consumption out of wealth, this paper shows that a wealth tax can play the same role and extends the result to a degrowth pathway. This has important policy implications because the viability of degrowth and a steady state no longer rely on a behavioral parameter alone, opening the way for functional finance. The paper presents an explicit balanced degrowth pathway, and then discusses more realistic degrowth pathways.

1. Introduction

It is by now well established that the impact of humanity's economic activity collectively exceeds the ecological carrying capacity of the planet. This is reflected in warnings that urgent action is required to achieve a liveable climate,[1] that no nation can serve as a template for a "good life for all" within planetary boundaries (O'Neill et al., 2018), that biodiversity and ecosystem function are deteriorating across the world (IPBES, 2019), and that humanity is continuing to exceed planetary boundaries (Richardson et al., 2023). Added to these warnings is the indisputable fact that much economic activity relies on a one-way flow of nonrenewable resources. Extraction of non-renewable resources reduces the amount left for the future, and the waste material places pressures on ecosystems.[2]

These biophysical realities show an urgent need to reduce material and energy throughput in the course of economic activity. In principle it is possible to support a substantial human population using considerably less resources than we do at present (e.g., see Millward-Hopkins et al., 2020). But we must not be under any illusions. There is at present *no* politically acceptable path to the "safe operating space" of Rockström et al. (2009), much less the "safe and just space" of Raworth (2013, 2017) and Rockström et al. (2023). There are many reasons for this, extending from the "sunshine problem" that a sustainability transition means "sunsetting" currently profitable enterprises (Ergen and Schmitz, 2023) to the weak political viability of effective macrofinancial regimes (Gabor et al., 2025) to the deep embedding of growth as a social and political priority in high-income countries (Albert, 2024).

It may be possible for economic output to rise in real monetary terms[3] while material and energy throughput declines. Absolute decoupling is required for economic growth to persist on a finite planet. However, in practice only relative decoupling is observed on

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[1] See the Intergovernmental Panel on Climate Change press release on the synthesis of the IPCC 6th Assessment Report.

[2] It is worth noting that the Hotelling rule, under which non-renewable resources would be phased down optimally over an indefinite future, appears to have no empirical relevance, whether in explaining the behavior of mining firms or in explaining resource prices (Livernois, 2009). Hotelling himself arguably never intended his rule to apply to mining; he understood the role of cumulative production on extraction costs and rate of extraction (Ferreira da Cunha and Missemer, 2020). Nevertheless, the main implication of his extended theory is that supplies of non-renewable materials are bell-shaped over time, while prices are U-shaped, which leaves us with the same sustainability challenge.

[3] That is, in monetary terms adjusted for inflation.

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a sustained basis[4] — that is, resource and energy use, as well as waste production, sometimes grow less rapidly than GDP, but they still grow (Haberl et al., 2020). Absent a proof that absolute decoupling is possible, degrowth theorists start with the stylized fact that persistent absolute decoupling has never been observed and argue that growth in monetary, and not only material, terms is unsustainable (Kallis et al., 2020). Indeed, some have argued that the possibility of decoupling has been definitively "debunked" (Parrique et al., 2019). They therefore reject appeals to decoupling as a way to reconcile business as usual economic activity with life on a finite planet (Kallis, 2018).

The rejection of decoupling as a possibility for the future can be challenged. In prior work, the author has provided a theoretical argument for why decoupling has not occurred in the past and indicated how that might be changed (Kemp-Benedict, 2018a). Similarly, Savin and van den Bergh (2022) have argued that weak policies explain the failure of greenhouse gas emissions to absolutely decouple from GDP. Their recommendation to abandon any growth-related targets – whether for growth or degrowth – is one that the author finds persuasive. However, their suggestion that potentially acceptable policy packages exist that can achieve decarbonization is less convincing. Acceptable policy packages must pass through the Overton Window,[5] and as noted above, currently acceptable policies will not achieve decoupling of the required depth and speed. While Savin and van den Bergh are almost certainly correct that degrowth ideas are not politically acceptable today, I would argue that their preferred package of a market for carbon, coupled with information provision and support for innovation, while more politically plausible, is still insufficient and arguably less likely to shift the Overton Window. The same could be said of my own proposal cited above. Moreover, the seeds for that shift may have already been sown, as Kallis et al. (2024) find support for what they call a "post-growth deal" as well as an "ecosocialist green deal" in the European Parliament, alongside the arguably more politically mainstream "liberal green deal". In short, I believe the degrowth theorists have a point (which Savin and van den Bergh, 2022, also accept; see p. 6) and it is not the purpose of the present paper to dispute it.

Where this paper will challenge (some of) the degrowth literature is on the role of advanced technology. The degrowth community, which includes both researchers and activists, displays ambivalence on the subject. Kerschner et al. (2018) describe a "love-hate" relationship between degrowth theorists and technology. A lack of consensus across the "degrowth spectrum", but also a tendency to see a need for modern technology, was documented by Eversberg and Schmelzer (2018), who found moderate agreement among participants at a degrowth conference for the proposition that high technology is necessary for a post-growth society, with a sizeable minority disagreeing. Perhaps the greatest ambivalence emerges around digital technologies, which are portrayed variously as: (positively) disruptive of the status quo (Gorz, 2010, p. 12); enabling small-scale production (Kostakis et al., 2018); and alienating people from nature and each other (Samerski, 2018).

Some influential degrowth authors argue that advanced materials and technology are necessary but not sufficient to meet environmental challenges and social needs. To take one example, Hickel (2020) writes, "Technology is absolutely essential in the fight against ecological breakdown. We need all the efficiency improvements we can get. But scientists are clear that they will not be enough, on their own, to fix the problem". And Kallis et al. (2020, p. 59) ask rhetorically, "Does the cause for degrowth reject technological advancements, marking a retrogression to the grueling labor of earlier times?" with the answer, "On the contrary, we recognize the role that large scale high-tech production will continue to play...".

This paper starts with the claim that much of the degrowth literature implicitly or explicitly requires an industrial "core" that provides processed commodities and bulk manufactures to support more dispersed "convivial" activities (Deriu, 2015; Kallis et al., 2018, p. 304). For example, the open-source XYZ ONESEATER spaceframe vehicle, which has been offered as an example of a convivial technology by degrowth activists, requires some general-purpose manufactures: stainless steel bolts and nuts; aluminum tubing; a polycarbonate sheet; and small parts made of polyethylene (PE), polyoxymethylene (POM), nylon, and steel. To those are added special-purpose manufactures, such as the crankset, pedals, chain, and wheels. For the rear wheel, the designers recommend a particular product from the manufacturer Shimano that features an internal 8-gear hub. Furthermore, the vehicle requires maintenance, including regular applications of grease.

Indeed, Deriu (2015, p. 81) notes that Ivan Illich, whose notion of "conviviality" – the transfer of needs provision from firms to broader society – has inspired many writers on degrowth and the larger degrowth community, did not advocate for abolishing industrial production altogether. Rather, he claimed that a convivial society must disrupt the industrial monopoly on meeting needs, while Vetter (2018, p. 1784) argues that conviviality is not dichotomous, or even a spectrum, but rather a complex mix of more and less convivial features.

The presence of an industrial core creates challenges for the political economy of degrowth. If materials are embodied in goods dispersed throughout the world, and the flow of resources is finite, then anyone in a position to influence that flow will have power; specifically, they will have "structural power" in the terms of Wright (2000). Furthermore, given the small penetration of convivial activities in economies today, it is unclear how they might spread until they dominate the industrial core. These issues will be explored, but not resolved, in the first part of this paper as a sketch of a broad research agenda. In a contribution to that agenda, the second part of the paper suggests a way to include both the industrial core and convivial activities in a stock-flow consistent post-Keynesian model. The model is "preliminary" in that it includes strong simplifying assumptions, both for clarity and to enable closed-form solutions. The paper therefore adds (however modestly) to the very small number of explicit macroeconomic degrowth models (Savin and van den Bergh, 2024).

The model is an adaptation and extension of a post-Keynesian steady-state model developed by Cahen-Fourot and Lavoie (2016). Steady-state models are relevant to degrowth because, as Kerschner (2010) argued, the long-run future towards which degrowth leads is a steady-state economy. Cahen-Fourot and Lavoie showed that a steady state with positive profits is possible if there is saving out of wealth, thus contradicting the claim of Kallis et al. (2020, p. 47) that a fixed economic pie entails zero net profit; similarly, van den Bergh et al. (2023) found that zero growth was compatible with a positive rate of interest. Cahen-Fourot and Lavoie's finding is consistent with that of Jackson and Victor (2015), who constructed a no-growth solution to a model that assumes saving out of wealth. Both Richters and Siemoneit (2017) and Hein and Jimenez (2022) confirmed the finding and expanded the analysis to consider stability, while Janischewski (2022) considered the consequences of nonlinear consumption out of wealth and wealth inequality. Barth and Richters (2019) carried out a stability analysis with linear consumption out of wealth in which production requires resources and generates waste heat.

A novel contribution of this paper is the introduction of a wealth tax to the post-Keynesian model, which proves to be important in that it opens the possibility for functional finance to enable degrowth and a steady state economy. In addition, and in contrast to Cahen-Fourot and Lavoie (2016) and Hein and Jimenez (2022), but like Barth

[4] Some weak evidence of absolute decoupling of consumption-based greenhouse gas emissions has been observed in some European countries, but it is not sufficient (Haberl et al., 2020; Vogel and Hickel, 2023).

[5] According to the MackinacCenter, where Overton developed the idea, "...politicians are limited in what policy ideas they can support — they generally only pursue policies that are widely accepted throughout society as legitimate policy options. These policies lie inside the Overton Window. Other policy ideas exist, but politicians risk losing popular support if they champion these ideas. These policies lie outside the Overton Window".

and Richters (2019), the model includes natural resources as an input to production. While absent in many post-Keynesian models, natural resources were considered by Fontana and Sawyer (2016), and both resources and wastes appear in the stock-flow-fund models of Dafermos et al. (2017) and Barth and Richters (2019).

Section 2 elaborates on the conceptual foundation of the model. Section 3 presents the essential accounting relationships that underlie the model. Section 4 applies the results of Section 3 to a balanced degrowth path and discusses extensions to more realistic paths. The implications of the model are discussed in Section 5. Section 6 concludes.

2. Conceptual elaboration

This section elaborates on the conceptual basis for the model, which is presented in the next section. By way of prelude, degrowth is an area of study, but is also a social movement. At the most basic level, degrowth researchers and advocates point to a problem – the unsustainability of growth as experienced in actual existing economies – and posit the necessary condition for the reduction of that problem – reversal of growth. But degrowth is not recession. Rather, it is an intentional downscaling of economic activity such that everyone can enjoy a good quality of life. So, at the next level they aim to provide positive alternatives to current ways of structuring societies, livelihoods, and provisioning of needs, with associated changes in behavior, institutions, and norms. Because they are trying to envision a world that does not yet exist, those alternatives are often partial, sometimes conflicting, and not obviously scalable. By the same token, the policy prescriptions arising from the degrowth literature have been characterized as weak (Savin and van den Bergh, 2022; Parrique, 2019). As these proposals are responding to extremely challenging systemic problems, it is hard to fault them if they fall short. Instead, the present paper takes the position that the current unsatisfactory state of those proposals indicates the need for further research. A similar point was made by Durand et al. (2024) in a call for "planning beyond growth". This paper is a contribution to that larger research agenda.

2.1. The convivial economy

The central degrowth concept adopted in this paper is that of "conviviality". In his book *Tools for Conviviality*, Illich (1973, p. 30) writes that, "A convivial society should be designed to allow all its members the most autonomous action by means of tools least controlled by others", where "tool" is defined very broadly to include institutions as well as physical tools. He notes that "convivial reconstruction demands the disruption of the present monopoly of industry, but not the abolition of all industrial production". Rather, a convivial society enables individuals and communities to pursue small-scale renewal by breaking the industrial monopoly over needs satisfaction.

Vetter (2018) applied anthropological techniques to the literature on conviviality and proposed a conceptual framework in the form of a matrix. Vetter's framework considers different *dimensions* across which conviviality can be assessed at a number of *levels*. The dimensions are:

- **Materials:** Harvesting, processing and disposal of raw matter
- **Production:** Assembling raw materials and pre-products
- **Use:** Procuring the task it was built for
- **Infrastructure:** Needed infrastructure for using

The levels are:

- **Relatedness:** What does it bring about between people?
- **Access:** Who can produce/use it where and how?
- **Adaptability:** How independent and linkable is it?
- **Bio-interaction:** How does it interact with living organisms?
- **Appropriateness:** What is the relation between input and output considering the context?

Drawing on the detailed discussion in Vetter (2018) around access and adaptability, convivial technologies use low cost materials, interoperable parts, and everyday tools that require skill but not specialized expertise. Regarding bio-interactions, convivial technologies make use of living processes – e.g., agriculture, silviculture, bioremediation – and promote healthy environments.

A concrete example of a convivial technology is provided by the Easy Reaper designed by Living Energy Farm.[6] According to the designer, it is "the simplest combine harvester ever created" and can be manufactured at scale for US$2000 per harvester after an initial investment of US$10,000. It can also be manufactured in small shops. It is adaptable, fuel efficient, and easily maintained. Among the many ways it can be adapted, because of its low energy requirements it is suitable for animal traction as well as motorized traction. This example demonstrates that convivial activities can be more or less formalized. A small firm can produce the Easy Reaper at scale and earn sufficient profit to expand. A farming community could build its own fleet of Easy Reapers and share them among its members. Regardless, to continue to qualify as a convivial technology, its production, distribution and use should foster positive relationships between people, while provisioning should respond to local needs through bottom-up control (Vetter, 2018).

Formal convivial production might reasonably be assumed to be carried out by labor-managed firms. Booth (1995) argues that worker cooperatives exhibit greater input efficiency than do corporations. Moreover, under conditions of full employment, cooperatives tend to be less growth-oriented than corporations. These conclusions are supported by (the admittedly limited) empirical evidence available to Booth in 1995. Meanwhile, research is ongoing into the source of asymmetries between labor-managed firms (LMFs) and capital-managed firms (KMFs). One key focus of research is to explain why LMFs are comparatively rare. Dow (2018) concludes a summary of the state of the research by arguing that LMFs are "not rare because they are dysfunctional. Rather, they are rare because they are seldom created from scratch, and because capitalist firms are seldom converted into LMF". Indeed, LMFs are efficient, productive, and robust. This suggests that appropriate institutional forms might be able to tip the balance towards LMFs and away from KMFs. However, this is an area for further research and will not be pursued further in this paper.

2.2. The industrial core

Activities in the industrial core resist being made convivial because of standardization, large separation between production and use, and large scale. They include: production of graded bulk commodities; large-scale provision of standardized intermediate goods; and widely-consumed but locally-specialized products. They also include the goods and services of the "foundational economy", which are best supplied in a top-down manner through extensive distribution networks and large-scale production (Foundational Economy Collective, 2022).

The model features a one-way interaction between the industrial core and the convivial economy through demand for the products of the industrial core by the formal convivial economy. However, the line between convivial and industrial production is not sharp. For example, eggs can be produced, graded, and sold locally to meet local needs under local control, but they can also be produced in large quantities. In contrast, a sufficient production of graded grains (e.g., the U.S. grade and class "Grade 2 Dark Northern Spring Wheat") requires extensive land, grain elevators, and distribution networks. Local sourcing would likely require the use of mixed grains of varying type and quality, likely resulting in a different type of bread. This would not necessarily be a bad outcome; indeed, the historic local specificity of available grains led to Germany's highly diverse bread culture, which has now been

[6] See: https://livingenergyfarm.org/the-easy-reaper/.

recognized by the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2023, p. 36). Note that the industrial core may feature labor-managed firms, together with capital-managed firms. A contemporary example is the US plywood industry, which includes several successful cooperative firms (Dow, 2018).

The model in this paper constrains the industrial core's use of resources. Note that in the degrowth literature, constraints on resources are not only biophysical. Rather, they are limited to a sustainable yield that takes into account ecosystem function, indigenous management, and governance of local commons. The envisaged sustainable flow must be not only technically possible (technical potential) and cost-effective (economic potential) but also acceptable (feasible potential). For the comparatively well-studied renewable energy sources, estimates for technical economic potential are, even taking uncertainty into account, much higher than projected electricity demand (Beaumelle et al., 2023). However, feasible potential is essentially unknown. The degrowth literature emphasizes sufficiency, social equity, and ecological sustainability, which suggests a comparatively low feasible potential under degrowth policies. Moreover, current observation of environmental overshoot strongly suggests that sustainable resource use will be below current levels.

The model does not apply a direct resource constraint to convivial activity because of the simplifying assumption that global resources in their raw form are only used by the industrial core, while global resources used by the convivial economy are embodied in goods purchased from the core. Any *direct* use of local resources by the convivial economy is presumed to be constrained through local common property rights regimes, of which many examples exist (Ostrom et al., 1999). This assumption considerably simplifies the analysis.

As noted in the Introduction, constraining the industrial core poses political economy challenges. This paper assumes that distributed resources will be managed through decentralized, "polycentric" forms of governance (Andersson and Ostrom, 2008), likely accompanied by changes in property rights (van Griethuysen, 2012). As documented by Ostrom (2010), a wide range of strategies already exists for managing and sustaining common-pool resources through polycentric systems – that is, through systems with many formally independent centers of decision making. For the more challenging task of managing global common resources, new systems can be designed by taking advantage of the strengths of different management regimes (Rose, 1999) and by innovating to bring systems to scale (Smith, 2017).

The complex and possibly self-organizing governance system is referred to in this paper as the "polycentric governance system", or PGS, while different centers within the PGS are referred to as "governance centers". The PGS is emphatically *not* a strong centralized state, which would be at odds with the concept of conviviality. The key roles of the government in the model are: (1) to manage the use of those resources needed by the industrial core; and (2) to purchase and distribute goods from the formal convivial economy. These activities should be seen as taking place at a range of scales and using different mechanisms.

2.3. Long-period positions vs. the distant future

A noted in the Introduction, we follow Kerschner (2010) by assuming that the long-run future towards which degrowth leads is a steady-state economy. As a counterpoint, Bonaiuti (2018, p. 1802) argues for cyclical models as against either steady growth or steady state. This paper accepts that cyclical patterns are important, not just as temporary disturbances from a central tendency, but as endogenous features that can lead to irreversible changes in economic systems. Nevertheless, this paper also accepts the notion of a steady state. The approach taken is akin to the "long-period analysis" of the classical economists (Kurz and Salvadori, 1998), although with a different set of adjusting variables. It is perhaps worth noting that classical analysis was developed in a time of rapid long-run change overlain by short-run cycles – just as envisaged by degrowth theorists along degrowth pathways.

Importantly, the classical "long-period position" is not a position that is ever actually realized. Rather, it is a characteristic of the economy at any given moment, a "center of gravitation" around which the economy cycles in the short and medium term. The center is not fixed; it moves due to exogenous and endogenous processes that play out over the long run. Thus, the "long period", which characterizes the economy at any moment, including the present, is distinct from the "long run", which characterizes the economy in the future. To avoid confusion, in this paper, "distant future" will be used instead of the more conventional phrase "long run". With this terminology, we reconcile Kerschner and Bonaiuti by arguing that a degrowth pathway tends in the *distant future* to a dynamic and ever-changing economy with a steady-state *long-period position*, and we call that a steady-state economy.

The key differences between conditions today and the distant future envisaged by this paper are: (1) the relative importance of convivial activity (marginal today, dominant in the distant future); and (2) ownership of natural resources (mainly private actors today, a polycentric governance system in the distant future).

3. Model accounts

The preceding sections have shown how layered and complex a degrowth analysis can become. At this point an explicit model is proposed that makes a number of strong simplifying assumptions. The purpose of those assumptions is to focus on the topic of interest in this paper: a degrowth pathway in which a predominantly industrial economy is replaced by a convivial economy with a small industrial core; and in which resources are removed from private hands and placed under a polycentric governance system. The model is an elaboration of the one proposed by Cahen-Fourot and Lavoie (2016), and some of their simplifications are carried over directly. Most importantly, there is no banking sector and no market in ownership shares of firms. Adding these important features of real economies is left to future work. As with Cahen-Fourot and Lavoie, households hold government bonds and capital stocks as wealth. This paper adds a further asset, in that households may own natural resources that provide them with rents.

The model is specified in terms of a set of stock-flow consistent (SFC) accounts. The SFC tables are shown first, followed by elaboration of output and saving.

3.1. Stock-flow consistent accounts

Stock-flow consistent models are specified in terms of a transactions flow matrix (TFM), a balance sheet, and a revaluation matrix. A TFM reflects quadruple-entry accounting (Godley and Lavoie, 2007, chap. 2) in which credits and debits balance in each transaction, while income and use of funds balance for each economic agent. In practice, that means that every row and every column sums to zero, as in the TFM for the proposed model in Table 1. In the model, firms in the industrial core and the formal convivial economy have both a current and a capital account. Households have two roles, both as users of goods and services, and as producers of (convivial) goods and services.

The balance sheet, shown in Table 2, records net accumulation of assets. The columns of the balance sheet sum to zero, but the rows need not. The accumulated capital stock, net of accumulated depreciation, has no counterpart entry that fully offsets it, and neither do natural resources.

The revaluation matrix, shown in Table 3, records changes in the value of resources and government bonds. For bonds, a rise in the value for households as an asset is balanced by a corresponding increase in the government's liability. In contrast, as natural resources have no counterpart, a rise (or fall) in value is not offset.

Table 1
Transactions flow matrix.

	Households		Formal convivial		Industrial core		PGS	Σ
	User	Producer	Current	Capital	Current	Capital		
Net formal consumption	$-C$		$+C$					0
PGS expenditure			$+G$				$-G$	0
Investment				$-I_c$	$+I$	$-I_i$		0
Industrial inputs			$-Z$		$+Z$			0
Household production		$-M$	$+M$					0
Household exchange	$-E$	$+E$						0
[*Production*]		$[H]$	$[Y_c]$		$[Y_i]$			
Wages	$+W$		$-W_c$		$-W_i$			0
Profits	$+\Pi$		$-\Pi_c$		$-\Pi_i$			0
Resource rents	$+p_r R_h$				$-p_r R$		$+p_r R_g$	0
Depreciation			$-D_c$	$+D_c$	$-D_i$	$+D_i$		0
HH mixed income	$+H$	$-H$						0
Saving	$-S$			$+\Delta K_c$		$+\Delta K_i$	$+\Delta B$	0
Interest	$+iB$						$-iB$	0
Resource transfers	$+A$						$-A$	0
Taxes net of transfers	$-T$						$+T$	0
Σ	0	0	0	0	0	0	0	0

Table 2
Balance sheet.

	Households	Form. Conv.	Ind. Core	PGS	Σ
Fixed capital	$+K$				$+K$
PGS debt	$+B$			$-B$	0
Natural resources	$+N_h$			$+N_g$	$+N$
−Net worth	$-\Omega$			$B - N_g$	$-(K + N)$
Σ	0	0	0	0	0

Table 3
Revaluation matrix.

	Households	PGS
Resource revaluation	$+V_h^R$	$+V_g^R$
Bond revaluation	$+V^B$	$-V^B$
Total	$+V_h$	$+V_g$

3.1.1. Transactions flow matrix

The TFM is presented first, with explanations given for each row.

Net formal consumption Referring to households as "users" rather than "consumers" emphasizes their role within a circular economy, purchasing function rather than product and engaging in reuse, refurbishment, and re-purposing (SEI and CEEW, 2022, p. 95). For this reason, the first row of Table 1 is labeled "Net formal consumption"; it is net of returns or refurbishment. But no economy can be fully circular, and the positive net recognizes that there must be some residual. Following convention, net consumption is labeled C. An explicit treatment of wastes and circular economy practices could follow the path laid by Dafermos et al. (2017), a topic left to future work. The corresponding transaction is expenditure by households and income for firms in the formal convivial economy.

PGS expenditure & Investment The polycentric governance system (PGS) also purchases from the industrial core (and, as a simplifying assumption, *not* from the convivial economy), a transaction recorded under "PGS expenditure". This expenditure at a minimum supports decent living standards through public infrastructure provision and maintenance and support for caring activities — the foundational economy (Foundational Economy Collective, 2022). In the "Investment" row, firms in the industrial core both produce and purchase investment goods, with the income recorded under the current account and the expenditure in the capital account.

Industrial inputs The "Industrial inputs" row records the purchase of intermediate goods to formal convivial production provided by the industrial core. The value of the goods is Z and the transaction is entered in the current account of both the formal convivial sector and the industrial core.

Household production & exchange The next two rows reflect the *monetary* component of the informal household economy. We emphasize that there can be a very large non-monetary component as well, or one that uses only local currencies. The first of the two rows, "Household production" records the purchases of goods and services from the formal convivial core that are used by households for home convivial production, M. This could include nuts and bolts, lumber, electronic components, fabric, machine rental, and so on. The row records a payment from households; the counterpart entry is the income to the formal convivial economy. The "Household exchange" row records expenditure and income between households. While expenditure and income net out to zero for households as whole, the transaction is recorded in Table 1 as expenditure by households in their role as users and income by households in their role as producers.

Production memo line The "[Production]" row is a memo line. Its entries are sums of the terms in the lines above. It shows that net output by the formal convivial economy, denoted by Y_c, is equal to sales of consumption goods, goods purchased by government, and intermediate goods for household convivial production, net of intermediates provided by the industrial core, Z. The equivalent income expression is the sum of wages W_c and profits Π_c, net of depreciation D_c. For the industrial core, total production of investment goods I and intermediate goods Z is balanced by wages W_i, profits Π_i, rents $p_r R$, and depreciation D_i. The difference between income and expenditure for monetized convivial production, $E - M$, is denoted by H. It represents value added in the monetized – but informal – part of the convivial economy.

Wages & Profits Households receive both wages and (net) profits from firms in the formal convivial economy and the industrial core. The model shares with Cahen-Fourot and Lavoie (2016) the assumption that households entirely own firms, and firms do not retain profits. This was introduced as a simplification by Cahen-Fourot and Lavoie, but it is worth noting that Richters and Siemoneit (2017, p. 122) found it to be a requirement for stability of the steady state in post-Keynesian models of the type considered in this paper. Stability is not considered in the present paper.

Resource rents Resource rents are a key feature of the model presented in this paper and were not included in the model of Cahen-Fourot and Lavoie (2016). Note that in national accounts, rents are included with profits. Accordingly, in terms of household income they are combined with profits. However, rents appear as costs to firms rather than a surplus, so it is useful to keep them separate.[7] Rents are paid on flows of materials, represented by R, with separate components for resources owned by households, R_h, and government, R_g. The total flow R is limited either by extractive capacity (in the unsustainable case) or sustainable yield (in the sustainable case). Sustainable yield is understood to include goals beyond maximum sustained extraction, encompassing ecosystem function, traditional livelihoods, and an allowance for locally managed common resources. The maximum resource flow consistent with extractive capacity is denoted by $\overline{R}$, while the sustainable flow is denoted by $\underline{R}$. In general, $\underline{R} < \overline{R}$, and $\underline{R} \leq R \leq \overline{R}$. Regarding the resource price p_r, up to this point no prices have been introduced into the model. However, resource flows cannot be equated to produced goods, and must be given a price.[8] The price of the final consumption good provides a *numéraire*, while the resource price p_r is a real price relative to the *numéraire*. The resource R is a commodity and p_r is a commodity price. When global stocks are sufficient to meet demand with a comfortable buffer, the futures price is slightly above the spot price to cover carrying cost and the opportunity cost of holding onto the stocks, which introduces a dependence on the interest rate. When stocks are low, the spot price rises, reflecting the "convenience yield", or the value of having stocks on hand to meet demand on the spot market. The price-induced reduction in demand and increase in supply leads to a gradual restoration of a normal level of stocks (see Kemp-Benedict, 2022b, for a discussion). Because commodity prices are strongly determined by physical conditions of supply and demand, this paper neglects the interest rate dependence of the resource price, and defers a treatment of commodity markets to a future paper.

Depreciation Depreciation is characterized by formal conventions, both for setting its value and for entering into the accounts. It is defined in the tax code, and is therefore somewhat artificial, but is meant to align with a real loss of utility and market value experienced by durable goods over time. While accumulated investment appears as a debit in a firm's capital account, accumulated depreciation is entered in a "contra account" that appears as a credit. The counterpart to accumulated depreciation is depreciation expense, which offsets income in the firm's current account. The "Depreciation" row captures these entries.

HH mixed income Net household income from convivial activities is the difference between gross income, E, and expenditure on industrial inputs to convivial production, M. The difference is labeled H in the table. As mixed income (that is, income that is not assigned explicitly to profits and wages), it enters as a transfer within a convivially producing household from the Producer account to the User account.

Saving Saving by households is allocated to the two assets that were treated in the paper by Cahen-Fourot and Lavoie (2016): capital stock and government bonds. Saving is a flow, so the allocation is split between changes in capital, ΔK, and bonds, ΔB. The other asset in the model is natural resources. In the model in this paper, natural resources are transferred from households to various governance centers within the polycentric governance system (and not in the opposite direction), and are recorded in a separate row.

Interest Different governance centers pay interest on bonds. For simplicity, they pay a uniform rate of interest i.

Resource transfers Renewable natural resources, which are a stock (or, in Georgescu-Roegen's terminology, a "fund": see Georgescu-Roegen, 1970; Marzetti, 2013; Dafermos et al., 2017), provide the resource flows R_h and R_g. Ownership is transferred from households to the government through government purchases, in an amount A. One crucial issue that is side-stepped in this paper is that the *nature* of the resource will change between an industrial-dominated economy and the steady-state economy. The resource flows in today's economy are drawn from stocks of geological deposits. However, in the steady-state economy resource flows will be produced from Georgescu-Roegenian funds of renewable resources. The switch from one to the other will have profound implications in terms of technology and political economy. Treatment of multiple resources with different characteristics is a complex topic that is left to future work.

Taxes net of transfers In the model, taxes are assessed on households alone. They represent expenditure for households and income for governance centers. From the prior rows, and reading along the "Households: User" column, households derive income from the industrial core, interest on bonds, resource rents, capital gains on resources, and purchases of resources by governance centers. They also derive income from household activities. The model assumes that all formal income is taxed at the same rate, τ, while informal household activities are not taxed. Furthermore, the model allows for a tax on wealth Ω at a rate τ_v,

$$T = \tau \left[W + \Pi + iB + p_r R_h + A\right] + \tau_v \Omega. \tag{1}$$

3.1.2. A note on GDP and decoupling

The "Production" memo line sheds some light on the vexed debate over decoupling material throughput from GDP. There are at least three ways in which GDP might be recorded for this economy. First, it could exclude informal household production. This could be called GDP_1:

$$\mathrm{GDP}_1 = Y_c + Y_i. \tag{2}$$

Alternatively, it could include every monetized exchange, including informal exchange between households. This gives

$$\mathrm{GDP}_2 = H + Y_c + Y_i. \tag{3}$$

Finally, it could also include the imputed value of non-monetized convivial exchange,

$$\mathrm{GDP}_3 = H + Y_c + Y_i + \text{imputed non-monetary transactions}. \tag{4}$$

Regarding this last item, while economic accounts today do include imputed values, those are largely for services provided by assets, such as imputed rental services from owned homes and the estimated value of firms' intangible property. A guidance note for valuing unpaid household services, in particular home care, has been endorsed for the 2025 update of the UN System of National Accounts.[9] However, at present such activities are recorded, if at all, in household satellite accounts. As part of a broader research agenda, future work could

[7] If the firms own the resources then rents must be imputed.

[8] A relative price should also distinguish the formal convivial sector from the industrial core. However, to keep an already complicated analysis more tractable, the treatment of relative prices in the formal economy is left to future work.

[9] Guidance note WS.3 from the Wellbeing and Sustainability Task Team.

draw on the emerging literature on macroeconomic modeling of care activities (Blecker and Braunstein, 2022), including the structuralist model of Braunstein et al. (2011).

Along the degrowth pathway presented later in this paper, GDP_1 almost certainly exhibits degrowth. However, GDP_2 and GDP_3 might or might not decline. The important point is that GDP_2 and GDP_3 are not particularly informative as measures of economic pressure on the natural environment, and as households can choose whether to charge for their activities or not, the difference between them is somewhat arbitrary. What matters in the model presented in this paper is the value of production from the formal economy, which is GDP_1. The key distinction for sustainability is that the industrial core is where natural resources are used in their raw form and the formal convivial economy is constrained by the need for intermediates from the industrial core.

Later in this paper an explicit "balanced degrowth" pathway is presented in which both GDP_1 and GDP_2 decline. However, an unbalanced transition is highly likely, and the model can in principle be extended in a "post-growth" direction in which GDP_1 almost certainly declines, whereas GDP_2 may not and GDP_3 almost certainly does not.[10]

3.1.3. Balance sheet

The first two rows of the balance sheet, shown in Table 2, record the total stock of fixed capital, K, and of government debt, represented by bonds B. Both are assets for households. There is no counter-party for whom fixed capital is a liability, so the row sum is equal to K. Bonds are, however, a liability for government, so the row sums to zero.

The next row is for natural resources. The value of natural resources is denoted in the model by N_x (where x is either h, for households, or g, for the government). In economic terms, the fundamental value for natural resources is given by the discounted value of the stream of payments arising from rents associated with the flow of products and services generated from the resource.[11] The convention adopted in this paper is to calculate the fundamental value based on extractive capacity rather than sustainable yield. The market price may be higher or lower than that fundamental value, given by a Tobin-q factor q.

In the model, resource flows associated with natural resources are denoted by R_x, where x is either h or g, while the (uniform) price is p_r. Maximum extractive capacity is denoted by $\overline{R}_x$ and sustainable yield by $\underline{R}_x$. Privately-owned resources are presumed to be operated at full capacity whenever economic conditions permit, so $R_h = \overline{R}_h$ in the long-period position. In contrast, resources under the PGS are presumed to satisfy $R_g = \underline{R}_g < \overline{R}_g$ in the long-period position.

Investors will compare potential income from rents to the alternative income from interest on bonds, so an appropriate discount rate is the bond rate i. Assuming that investors do not price in degradation, the stream of payments can extend arbitrarily far into the future, so the value N_x is

$$N_x = \frac{qp_r}{i}\overline{R}_x \equiv qN_x^{\text{fund}}. \tag{5}$$

In the final expression, the fundamental value N_x^{fund} is set equal to $(p_r/i)\overline{R}_x$.

Both the price and the interest rate can change, and the allocation of resources between households and government can change as well. If, between one time and another, $p_r \to p_r'$, $i \to i'$, $q \to q'$, and $\overline{R}_x \to \overline{R}_x + \Delta\overline{R}_x$, then the change in the value of the resource, ΔN_x, is given by

$$\Delta N_x = \frac{q'p_r'}{i'}\Delta\overline{R}_x + \left(\frac{q'p_r'}{i'} - \frac{qp_r}{i}\right)\overline{R}_x. \tag{6}$$

The row in Table 1 labeled "Resource transfers" is associated with changes in $\overline{R}_x$, so entries in that row can be identified with the first term in this equation,

$$A = \frac{q'p_r'}{i'}\Delta\overline{R}_g = -\frac{q'p_r'}{i'}\Delta\overline{R}_h. \tag{7}$$

The resource revaluation row in the revaluation matrix in Table 3 is associated with changes in the resource price and interest rates, so the entries are given by

$$V_x^R = \left(\frac{q'p_r'}{i'} - \frac{qp_r}{i}\right)\overline{R}_x. \tag{8}$$

3.2. Output

The model in this paper is informed by both classical and post-Keynesian theory and in many particulars follows the approach taken by Cahen-Fourot and Lavoie (2016). The output of interest is that of the formal economy, which consists of the formal convivial economy and the industrial core. It is given by time-varying technical coefficients that are fixed in the short run. The coefficients are productivities that change due to innovations that take time to discover, evaluate, and implement.

Capital productivity in sector m is denoted by κ_m and labor productivity by λ_m. Resource productivity in the industrial core (sector i), or "primary" productivity, is denoted by ν_{prim}, while the productivity of industrial inputs to the formal convivial economy (sector c) is denoted by ζ. With these definitions, output from each sector is determined by the most constrained input:

$$Y_c = \min\left(\kappa_c K_c, \lambda_c L_c, \zeta Z\right), \tag{9a}$$

$$Y_i = \min\left(\kappa_i K_i, \lambda_i L_i, \nu_{\text{prim}} R\right). \tag{9b}$$

Note that in standard post-Keynesian theory, potential production is determined by the capital stock. Labor availability normally exceeds demand and (implicitly) resource flows can adjust to meet demand. The model presented in this paper assumes that a normal degree of capacity utilization is built into productivities, so in the long-period position with only normal levels of slack,

$$Y_c = \kappa_c K_c = \lambda_c L_c = \zeta Z, \tag{10a}$$

$$Y_i = \kappa_i K_i = \lambda_i L_i = \nu_{\text{prim}} R. \tag{10b}$$

For the formal economy as a whole, total output is $Y = Y_c + Y_i$, the capital stock is $K = K_c + K_i$, and labor is $L = L_c + L_i$. With production shares $\eta_m = Y_m/Y$, the aggregate labor and capital productivities are weighted harmonic means,

$$\frac{1}{\lambda} = \frac{\eta_c}{\lambda_c} + \frac{\eta_i}{\lambda_i}, \tag{11a}$$

$$\frac{1}{\kappa} = \frac{\eta_c}{\kappa_c} + \frac{\eta_i}{\kappa_i}. \tag{11b}$$

The value of industrial intermediate goods Z cancels out when computing the total value of output from the formal economy, as seen in row "industrial inputs" in Table 1, so there is no analogue to ζ in the aggregate model. The aggregate resource productivity is

$$\nu = \frac{\nu_{\text{prim}}}{\eta_i}. \tag{12}$$

As noted above in the discussion of the TFM, the maximum resource flow consistent with extractive capacity is denoted $\overline{R}$, while the sustainable flow is denoted by $\underline{R}$, with R satisfying $\underline{R} \le R \le \overline{R}$.

[10] Van den Bergh prefers the term "a-growth" (van den Bergh, 2011) to "post-growth", while Savin and van den Bergh (2022) claim that post-growth is sometimes used as a euphemism for degrowth. However, "post-growth" has currency, it is not always employed as a euphemism, and it is not used that way here. Indeed, in practice, "degrowth" increasingly refers to the transition, while "post-growth" describes the distant future of a dynamic and ever-changing steady-state economy.

[11] The "fundamental value" referred to here corresponds to what a trader might call "fundamentals". It is a value against which to measure whether the market is overvaluing or undervaluing a tradeable asset. It is *not* fundamental in the sense of value theory. Commentary on value theory is abundant in the ecological economics literature. For an overview, see O'Neill and Spash (2000). To get a sense of the debates, see Pirgmaier (2021) and the response by Røpke (2021).

3.3. Saving

Households make net purchases of goods and services for their own consumption from the formal convivial sector. As noted above, purchases are net of circular economy activities such as returns, refurbishment, or recycling. In Table 1, net consumption is denoted by C. Households also engage in informal convivial activities. Household producers use formal convivial goods, recorded as M in Table 1. However, across all households exchange cancels out, $+E - E = 0$. Taken as a whole, household net purchases are from the formal economy, and the value of those purchases is $C + M$. Households pay for those purchases out of their income and wealth.

Consistent with Cahen-Fourot and Lavoie (2016), the model assumes no saving from after-tax wages and a consumption rate c_v on wealth. They also applied a saving rate s_p from after-tax profits and interest; we apply the same rate to rents, which are a form of profits. A question arises how to treat the wealth tax. If, during a year, a household's profit and interest income were precisely offset by its wealth tax, we assume that they would treat that result as nullifying their profits. We therefore apply the saving rate s_p to after-tax profits and interest net of the tax on wealth. The household expenditure balance can then be written

$$C + M = (1-\tau)W + (1-s_p)(1-\tau)\left(\Pi + iB + p_r R_h + A\right) \\ -(1-s_p)\tau_v\Omega + c_v\Omega. \tag{13}$$

Summing the two Households columns in Table 1 provides a separate equation for $C + M$,

$$C + M = W + \Pi - T - S + iB + p_r R_h + A, \tag{14}$$

and combining Eqs. (1), (13), and (14) gives an expression for household saving,

$$S = s_p(1-\tau)\left(\Pi + iB + p_r R_h + A\right) - (c_v + \tau_v s_p)\left(K + B + N_h\right). \tag{15}$$

The relative size of the coefficients on the two terms in Eq. (15) is important for the steady-state. To show this, we define a new composite parameter

$$\theta \equiv \frac{c_v + \tau_v s_p}{s_p(1-\tau)} = \frac{c_v}{s_p(1-\tau)} + \frac{\tau_v}{1-\tau}. \tag{16}$$

Hein and Jimenez (2022, p. 55) find that this parameter, with $\tau_v = 0$, must lie between the interest rate on bonds i and the profit rate r for a steady state to be possible.[12] We now reproduce this result.

In terms of θ, the saving equation can be written

$$S = s_p(1-\tau)\left(\Pi + iB + p_r R_h + A - \theta K - \theta B - \theta N_h\right). \tag{17}$$

Further using the definition of the profit rate to write $\Pi = rK$ and expressions for the value of resource rents from above, we can write $p_r R_h = p_r \overline{R}_h = iN_h^{\text{fund}}$ and $N_h = qN_h^{\text{fund}}$, so

$$S = s_p(1-\tau)\left[(r-\theta)K + (i-\theta)B + (i-q\theta)N_h^{\text{fund}} + A\right]. \tag{18}$$

We now show the relevance of θ to the long-period position.

When there is an equilibrium (however arrived at) in the market for natural resources, there will be no transfers of natural resources ($A = 0$) and market values for natural resources will reflect fundamentals ($q = 1$). These values characterize a long-period position for the model. Under those conditions, Eq. (18) becomes

$$S = s_p(1-\tau)\left[(r-\theta)K + (i-\theta)B + (i-\theta)N_h\right]. \tag{19}$$

Bonds have zero risk – they will be paid as long as the polycentric governance system endures – while investment in the industrial core is risky. For that reason, a precondition for investment in firms is that $r > i$. Examining Eq. (19), that implies that for savings to be positive or zero in the long-period position it is necessary that $r > \theta$, so that at least one term in the equation is positive. The two cases of interest are: a) $r > i > \theta$; or b) $r > \theta > i$. In case (a), saving can never be zero in the long-period position; in case (b) it can. Thus, *a steady-state economy requires that* $r > \theta > i$. This is the result found by Hein and Jimenez (2022, p. 55).

Values for parameters that might hold today are $\tau_v = 0$/year, $c_v = 0.01$/year, $\tau = 0.30$, and $s_p = 0.80$. With those values, $\theta = 1.8\%$/year. Using data from FRED, in the United States, between 1954 and 2023, the 10-year bond rate fell below that level in only 42 months out of 840, or 5% of the time. Thus, under historical conditions, case (a) would hold, meaning that zero savings would not be possible in the US historical context.[13]

In principle, θ can be brought above i by changing the income tax rate τ without imposing a wealth tax. However, keeping the same values as above for c_v and s_p, for θ to equal 5%/year, τ would have to be 0.75. That is a very high average income tax rate. Imposing a wealth tax brings the second term in Eq. (16) into play. Unlike the first term, the second term depends solely on tax rates, with no behavioral parameters. Moreover, with $\tau = 30\%$, the second term alone is equal to 5%/year when $\tau_v = 3.5\%$/year. This suggests that a steady state can be made possible by imposing a wealth tax and, possibly, increasing the income tax.

Using fiscal policy to achieve policy goals fits the spirit, if not the letter, of Lerner's notion of "functional finance" (Lerner, 1943). Lerner's policy goals were different, but his lesson still applies, that "Policies should be judged on their ability to achieve the goals for which they are designed and not on any notion of whether they are 'sound' or otherwise comply with the dogmas of traditional economics" (Forstater, 1999, p. 476). Together, an income and a wealth tax provide considerable leverage over the value of the parameter θ. This is particularly important given the finding of Janischewski (2022, Table 2) that a declining marginal propensity to consume out of wealth results in an even tighter constraint on the interest rate.

4. Degrowth paths

Along any degrowth path, households must maintain net negative savings and thus a value for θ that lies above i (and possibly also r). Beyond this condition, there are many ways in which to specify behaviors and close the model.

For any closure, this paper assumes that the degrowth path starts with all resources – which are presumed to be renewable – in private hands. Private owners manage resources unsustainably, with strong incentives to use all of the available extractive capacity. For example, if the renewable resource is farmland, private owners may grow a single crop with intensive use of inputs. While there will be departures during booms and slumps, the long-period position at the start of the degrowth path is $R_{h0} = \overline{R}$, $R_{g0} = 0$.

Along the degrowth path, various governance centers within the polycentric governance system buy rights to resource flows from households, so the parameter A in Table 1 is positive. Those purchases are presumed to follow the principle of eminent domain with fair compensation,[14] where fair compensation is taken to be the fundamental valuation before the payments commence. So, when calculating A, q is set to one, while p_r and i are kept at their initial values p_{r0} and i_0. As the government is taking over management of the resource, it effectively

[12] They further show that it must lie within an even tighter band for the steady state to be stable, but we do not explore stability in this paper.

[13] As of this writing (April 2025) the outlook for the US economy is highly uncertain. Whatever eventually transpires, even if it is a collapse of the US economy, the US is emphatically *not* pursuing a degrowth strategy.

[14] Eminent domain, also known as "compulsory acquisition" and "compulsory purchase", is the power of government to take private property for public use without consent of the owner.

pays for a transfer of extractive capacity from private to public control, denoted $\Delta\overline{R}$, although it will subsequently supply the resource at the lower, sustainable, extraction rate. The payment A is therefore given by

$$A = \frac{p_{r0}}{i_0}\Delta\overline{R}. \tag{20}$$

The realized values of q, p_r, and i that prevail in private markets may diverge from those used by governance centers as the basis for fair compensation, but the value based on the fair compensation principle is not affected.

At the end of the degrowth pathway, all resources are in the hands of one or several governance centers. In contrast to private owners, the polycentric governance system manages resources in a sustainable manner, so at the end of the transition, $R_h = 0$, $R_g = \underline{R}$. Along the degrowth pathway,

$$\Delta R_h = -\Delta\overline{R}, \tag{21a}$$

$$\Delta R_g < +\Delta\overline{R}. \tag{21b}$$

For simplicity, a straight-line transfer over time is assumed, over a period t_{DG} – the duration of the degrowth transition – and the ratio of sustainable yield to extractive capacity is assumed to be uniform. In that case,

$$\Delta\overline{R} = \frac{\overline{R}}{t_{\mathrm{DG}}} \quad \Rightarrow \quad A = \frac{p_{r0}\overline{R}}{i t_{\mathrm{DG}}}, \tag{22}$$

and at time t,

$$R_h = \left(1 - \frac{t}{t_{\mathrm{DG}}}\right)\overline{R}, \tag{23a}$$

$$R_g = \frac{t}{t_{\mathrm{DG}}}\underline{R}, \tag{23b}$$

$$R = R_h + R_g = \overline{R} - \frac{t}{t_{\mathrm{DG}}}\left(\overline{R} - \underline{R}\right). \tag{23c}$$

The growth rate of resource use is

$$\hat{R} = \frac{\dot{R}}{R} = -\frac{\overline{R} - \underline{R}}{t_{\mathrm{DG}}\overline{R} - t\left(\overline{R} - \underline{R}\right)}. \tag{24}$$

The available resource thus declines at a rate that starts at $(1-\underline{R}/\overline{R})/t_{\mathrm{DG}}$ at $t = 0$ and ends at $(\overline{R}/\underline{R} - 1)/t_{\mathrm{DG}}$ at $t = t_{\mathrm{DG}}$. Because $\underline{R} < \overline{R}$, this leads to a rising rate of decline. For example, if sustainable yield is half the extractive capacity, over a 50-year transition period t_{DG}, $\hat{R}$ declines at a rate that goes from −1%/year at $t = 0$ to −2%/year at $t = t_{\mathrm{DG}}$.

We now add further assumptions for an explicit but highly simplified closure, in which many parameters are held fixed, followed by a discussion of possible extensions to achieve a more realistic closure.

4.1. Balanced degrowth path

In this section we propose a balanced degrowth path. It is expressed in terms of the aggregate formal economy, consisting of both the formal convivial economy and the industrial core (see Section 3.2). For the formal economy, total output is $Y = Y_c + Y_i$ and similarly for labor L, capital K, wages W, profits Π, and depreciation D. Industrial intermediates Z net out and play no explicit role in the formal economy.

Along the balanced path, total output, output from the formal convivial economy and the industrial core all decline at the same rate, so the output shares η_c and η_i in Eq. (11) are constant. Furthermore, Y is assumed to decline at the same rate as resources and both capital and labor adjust in line with reduced output. With no pressure on inputs, cost shares and prices are stable, and we can assume that $\hat{\kappa} = \hat{\nu} = 0$, while p_r is constant. When these conditions hold,

$$\hat{Y} = \hat{K} = \hat{R} = \hat{\lambda} + \hat{L}. \tag{25}$$

We do not explicitly address employment and labor productivity in this paper. However, it would be consistent with the conceptual model of the economy for labor productivity to rise in the industrial core, thereby shedding workers, and either grow slowly or not at all in the convivial economy. The subject of employment and wage-setting is left to future work.

We further assume that the interest rate i does not change. To keep interest rates steady, the volume of bonds is presumed not to change. The cost of buying resources is therefore covered entirely through higher taxes. With no pressure on resources, and a guaranteed payment for resources from the government, market values are at their fundamental levels ($q = 1$), so there is no revaluation of resources.

We emphasize that the purpose of the balanced path is not realism, but rather to provide a benchmark for discussing alternatives. Some alternatives are discussed in Section 4.2 by way of introducing a research agenda.

Because $\hat{R} < 0$, the capital stock is declining, as is production from the industrial core. This is indisputably a degrowth path. The path of R, K, and Y can be expressed in terms of a "sustainability contraction factor" $\sigma = 1-\underline{R}/\overline{R}$; for example, if sustainable yield is half the installed extractive capacity, $\sigma = 0.5$. In terms of this parameter,

$$K = K_0\left(1 - \frac{t}{t_{\mathrm{DG}}}\sigma\right). \tag{26}$$

As the volume of bonds B does not change, the "Saving" row in Table 1 shows that $S = \Delta K = -K_0\sigma/t_{\mathrm{DG}}$. Substituting this and the above into the expression for saving given in Eq. (15) shows that

$$\begin{aligned} -K_0\frac{\sigma}{t_{\mathrm{DG}}}\delta =& s_p(1-\tau)\left[rK_0\left(1 - \frac{\sigma t}{t_{\mathrm{DG}}}\right) + i_0 B_0 + p_{r0}\overline{R}\left(1 - \frac{t}{t_{\mathrm{DG}}}\right)\right] \\ &- (c_v + \tau_v s_p)\left[K_0\left(1 - \frac{\sigma t}{t_{\mathrm{DG}}}\right) + B_0 + \frac{p_{r0}}{i_0}\overline{R}\left(1 - \frac{t}{t_{\mathrm{DG}}}\right)\right] \\ &+ s_p(1-\tau)\frac{p_{r0}}{i_0}\frac{\overline{R}}{t_{\mathrm{DG}}}\delta. \end{aligned} \tag{27}$$

In this expression, δ is an indicator for the degrowth transition, with

$$\delta = \begin{cases} 1, & t \in [0, t_{\mathrm{DG}}], \\ 0, & t \notin [0, t_{\mathrm{DG}}]. \end{cases} \tag{28}$$

Eq. (27) consists mainly of initial values, as indicated by the subscript "0". They therefore do not change over time. To make the equations more compact and to facilitate estimation, note that

$$\frac{p_{r0}\overline{R}}{K_0} = \rho\kappa, \tag{29}$$

where ρ is the resource cost share of output from the industrial core and κ is capital productivity. This is true at $t = 0$, where all resources are supplied by the private sector, so $R = \overline{R}$. Moreover, it remains true over time because along the balanced degrowth pathway ρ and κ do not change. Furthermore, defining β_0 as the initial ratio of governance center debt to industrial core output, B_0/Y, the ratio of governance center debt to the initial capital stock is

$$\frac{B_0}{K_0} = \beta_0\kappa. \tag{30}$$

With these definitions, and dividing Eq. (27) through by K_0 gives

$$\begin{aligned} -\frac{\sigma}{t_{\mathrm{DG}}}\delta = s_p(1-\tau)&\left[r\left(1 - \frac{t\sigma}{t_{\mathrm{DG}}}\right) + i_0\beta_0\kappa + \left(1 - \frac{t}{t_{\mathrm{DG}}}\right)\rho\kappa + \frac{\rho\kappa}{i_0 t_{\mathrm{DG}}}\delta\right] \\ -(c_v + \tau_v s_p)&\left[\left(1 - \frac{t\sigma}{t_{\mathrm{DG}}}\right) + \beta_0\kappa + \left(1 - \frac{t}{t_{\mathrm{DG}}}\right)\frac{\rho\kappa}{i_0}\right]. \end{aligned} \tag{31}$$

This equation determines the tax rate τ across the degrowth path. Four moments are of interest: the start ($t = 0$) and end ($t = t_{\mathrm{DG}}$) of degrowth, either during ($\delta = 1$) or immediately before or after ($\delta = 0$) the transition. Solving for τ under those conditions produces expressions for the tax rate shown in Table 4.

A minimal requirement for a transition is that the income tax rate be less than one. For that to hold, the numerators in the fractions that

Table 4
Expressions for the income tax rate at the beginning and end of the degrowth path, both during the transition ($\delta = 1$) and immediately before and after ($\delta = 0$).

Period	t	δ	Income tax rate τ
Just before	0	0	$1 - \dfrac{(c_v + \tau_v s_p)(1 + \beta_0\kappa + \rho\kappa/i_0)}{s_p(r + i_0\beta_0\kappa + \rho\kappa)}$
Start	0	1	$1 - \dfrac{1}{s_p}\dfrac{(c_v + \tau_v s_p)(1 + \beta_0\kappa + \rho\kappa/i_0) - \sigma/t_{DG}}{r + i_0\beta_0\kappa + \rho\kappa + \rho\kappa/(i_0 t_{DG})}$
End	t_{DG}	1	$1 - \dfrac{1}{s_p}\dfrac{(c_v + \tau_v s_p)(1 - \sigma + \beta_0\kappa) - \sigma/t_{DG}}{r(1-\sigma) + \rho\kappa/(i_0 t_{DG})}$
Just after	t_{DG}	0	$1 - \dfrac{(c_v + \tau_v s_p)(1 - \sigma + \beta_0\kappa)}{s_p r(1-\sigma)}$

appear in Table 4 must be positive. The most constraining condition is at the end of the transition, with $t = t_{DG}$ and $\delta = 1$. This gives a condition for the duration of the transition t_{DG},

$$t_{DG} > \frac{1}{c_v + \tau_v s_p}\frac{\sigma}{1 - \sigma + \beta_0\kappa}. \tag{32}$$

The second fraction on the right-hand side of this inequality is likely to be on the order of one. For example, if the sustainability contraction factor $\sigma = 0.5$, the government debt-to-output ratio $\beta_0 = 100\%$, and capital productivity $\kappa = 0.25$/year, then $\sigma/(1-\sigma+\beta_0\kappa) = 2/3$. The order of magnitude of the duration of the transition is therefore determined by consumption out of wealth and the wealth tax. If $c_v = 0.01$/year and $\tau_v = 0$, characteristic of today, then the transition must take on the order of a century if payments for resource transfers are paid out of taxes. However, if $c_v + \tau_v s_p = 0.05$/year, then the minimum duration shrinks to about two decades.

4.2. More realistic degrowth paths

As noted earlier, the balanced degrowth path is not a realistic pathway, even if degrowth policy were widely accepted. Even more realistically, degrowth is unlikely to be generally accepted, and the institutional changes needed for degrowth pose profound challenges (Klitgaard and Krall, 2012). More realistic pathways require a more complex model that includes a better specification of: governance arrangements; employment; needs satisfaction, including the foundational and care economies; finance beyond bonds; explicit reuse, repurposing, and recycling of goods and materials; pricing behavior, including for commodities; and technological change.

A sustainability transition in any form is more likely to exhibit unbalanced growth (Kemp-Benedict, 2018b). The unbalanced growth path will be influenced by public policy, resource availability, and firm and investor behavior. Among potential public policies should be included mission-driven public investment (Semieniuk and Mazzucato, 2019) and the creation of appropriate innovation systems (Altenburg and Pegels, 2012). Beyond biophysical resource constraints, resource availability is strongly influenced by the property system (van Griethuysen, 2012) and relevant governance arrangements (Smith, 2017) as well as the extent and effectiveness of circular economy practices. Firm and investor behavior, in turn, are influenced by the preceding factors as well as financial regulation and the prevailing interpretation of fiduciary duty (Freshfields Bruckhaus Deringer, LLP, 2021).

Reducing resource flows from the level achievable from extractive capacity, $\overline{R}$, to the sustainable yield, $\underline{R}$, means that the amount of capital in production must shrink. That, in turn, means that some firms must either close entirely or retire some of their profitable capital — the "sunshine problem" (Ergen and Schmitz, 2023). That can be achieved in principle through regulation (e.g., closing inefficient plants) or through public purchases. However, it can also be achieved through price competition over the smaller amount of resources. If the latter, then as production is restricted to sustainable levels, p_r can be expected to rise. Even though various governance centers are paying a fixed rate based on the initial price level p_{r0}, for a while private resource owners can enjoy the higher prices. Anticipation of rising prices could lead to high demand for resources as an asset, and therefore a higher value of Tobin's q. Were p_r to rise, the resource cost share $\rho = p_r/\nu$ would rise as well, inducing a rise in resource productivity, ν, at least for as long as that is biophysically possible. At the end of the transition, the cost share ρ is likely to have increased, the price p_r will be higher, and the productivity ν will be higher as well (see Kemp-Benedict, 2022a, Sec. 5.2, 5.3).

A further alternative is that governance centers could pay for resource transfers through bond issues rather than taxes. The result will essentially be a transfer of household wealth from natural resources to public bonds. However, as the volume of bonds rises, the interest rate i can be expected to rise as well. Resource prices p_r may be rising due to competition, but as the interest rate i rises, the value of resources may increase or decrease depending on how the ratio p_r/i changes. Note that regardless of the change in resource productivity, this model features 100% rebound. Any increase in efficiency translates into increased output if the resources are available. The communally-imposed constraint on resource use is therefore crucial. If cost share-induced technological change leads to a rise in resource productivity ν, then resource-constrained output from the industrial core, equal to $\nu\underline{R}$, will be higher than along the balanced degrowth path, although it will likely be below the initial output.

5. Discussion

This paper extended the model of Cahen-Fourot and Lavoie (2016) for a steady-state economy to the case of degrowth. Engaging with the degrowth literature highlights the problems that arise when applying models developed for capitalist economies to the various conceptualizations of a degrowth economy. This paper takes seriously the notion of a "convivial" economy (Deriu, 2015) and argues that conviviality requires a persistent, albeit restricted, industrial core. The paper aimed to show that the industrial core can be treated with the analytical tools of classical and post-Keynesian economics, which were originally developed for capitalist economies. Convivial activity itself is dealt with by having all direct resource extraction take place in the industrial core. The convivial economy accesses resources only as embodied in goods and services produced by the core. With this assumption, only that part of the convivial economy that involves monetary exchange appears in the model, made up of a (potentially large) formal convivial sector and informal household production and exchange.

The resulting model includes natural resources as an asset, a step that has not been taken in previous post-Keynesian steady-state models, such as those surveyed by Richters and Siemoneit (2017). Along a degrowth path, resources are taken out of private hands into communal management by various governance centers within a polycentric governance systems (Ostrom, 2010). The transfer is explicitly represented in the model as arising from eminent domain following a fair compensation principle. The polycentric governance system is assumed to restrict resource flows to a sustainable yield. That yield is below the growth rate of the resource to account for ecosystem function, indigenous management, and governance of local commons. The sustainable yield is expected to be much lower than that possible through the available extractive capacity, leading to the degrowth of at least the industrial core. Furthermore, an explicit balanced degrowth pathway presented in the paper exhibits degrowth for the overall economy, but that is not guaranteed for a more general – and realistic – model. The necessity of degrowth remains an open question.

The paper reconfirms the finding of Hein and Jimenez (2022) that a particular combination of model parameters is a key degrowth indicator, and expands it to include a wealth tax. The parameter $\theta = c_v/s_p(1-\tau) + \tau_v/(1-\tau)$ must lie between the bond rate i and the profit rate r for a steady-state solution to be possible. This parameter increases with consumption out of wealth, c_v, and decreases with saving out of profits, s_p. Both of these parameters characterize individual behavior and are out of the direct control of governance centers. But θ also increases when either of the tax rates τ or τ_v rise, opening the possibility of a form of functional finance (Lerner, 1943; Forstater, 1999), in which the tax code is used to achieve policy goals.

As with the steady state, the possibility of degrowth over a meaningful timescale depends on the combination of consumption out of wealth and the wealth tax. Along the balanced degrowth pathway, in which purchases of resources by governance centers under eminent domain are paid for out of taxes, the tax rate is less than one only if the duration of the transition exceeds a time on the order of $1/(c_v + \tau_v s_p)$. Typical values today are $c_v = 0.01$/year and $\tau_v = 0$, implying a minimum duration of about a century. For degrowth to be a feasible path, it will be necessary to increase consumption out of wealth, impose a wealth tax, or both. Indeed, both might be merited. For some individuals, accumulation of wealth might be a goal in itself; a wealth tax can offset this behavior. Other individuals today avoid consuming out of wealth during their earning years to compensate for a weak social safety net; strengthening the social safety net could permit them to increase their consumption out of wealth before retirement.

The steady-state is viewed in this paper as the end of a degrowth path, as proposed by Kerschner (2010). That end result is path-dependent; different ways of achieving the reduction in output produce different paths for resource, capital, and labor productivity. The resulting economy is constrained by the final value of the resource productivity and the sustainable yield: in steady state, $Y \leq \nu \underline{R}$. Because sustainable yield is determined outside of the economy by biophysical and cultural factors, the size of the economy depends on the productivity ν. This implies full rebound: if productivity rises, the economy expands. The key in the model to constraining the size of the economy is the governance of resource inputs that lie at the base of the economy. This is the geometric point at the bottom of Daly's "inverted pyramid" (Daly, 1995; Kemp-Benedict, 2014; Cahen-Fourot et al., 2020), and its centrality makes it a key lever in achieving degrowth.

6. Conclusion

To the extent that a degrowth path features a switch to a "convivial" economy, it will continue to rely on industrial production. Along such a path, in addition to a sharp reduction in the scale of industrial activity, industry loses its monopoly on meeting needs (Deriu, 2015). This paper introduced a preliminary model of a mixed convivial-industrial economy that allows for a treatment of a balanced degrowth path between an industrial-dominated to a convivial-dominated economy. It is preliminary in that more features must be added to it in order to carry the analysis beyond the balanced degrowth path.

The model presented in this paper is an extension of the steady-state model of Cahen-Fourot and Lavoie (2016). As in that model, in this paper consumption out of wealth makes positive profits possible in a steady-state economy. Richters and Siemoneit (2017) showed moreover that consumption out of wealth must be sufficiently high, a finding refined by Hein and Jimenez (2022) and reproduced in this paper. This paper additionally demonstrates that a wealth tax can add to or substitute for consumption out of wealth, opening the possible for functional finance to enable a steady-state economy. The paper further showed that along a balanced degrowth pathway, the duration of the degrowth transition is controlled by the combination of consumption out of wealth, saving out of profits, and the wealth tax.

While the specific model presented in this paper contains numerous simplifications, it offers a starting point for further development. In terms of method, it demonstrates a strategy for analytically separating industrial from convivial activity. In terms of results, it shows the need for consumption out of wealth, a wealth tax, or both, for degrowth to be possible.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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