The industrial core of a degrowth economy

Eric Kemp-Benedict[a]

[a] *Sustainability Research Institute, University of Leeds School of Earth and Environment, Leeds, LS2 9JT, UK*

Abstract

The degrowth literature argues that growth in monetary, and not only material, terms is unsustainable and rejects appeals to decoupling to reconcile economic activity with life on a finite planet. But it assumes the continued availability of advanced materials and technology, and anticipates that innovation is required to meet future needs. This paper argues that much of the degrowth literature implicitly or explicitly requires an industrial "core", within which technological innovation remains vital and productivity growth is expected. The paper introduces a stylized dual-economy model with a "convivial" economy that predominates in everyday life, together with an industrial core populated by private firms that innovate to compete on the basis of profitability. Drawing on prior post-Keynesian theory, which has shown 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 derives that result for the industrial core. It then 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 just-right "goldilocks" degrowth pathway, and then discusses more realistic degrowth pathways.

Keywords: degrowth, social ecological economics, classical economics, post-Keynesian, stock-flow consistent
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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

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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), and that biodiversity and ecosystem function are deteriorating across the world (IPBES, 2019). Added to these warnings is the indisputable fact that much economic activity relies on a one-way flow of nonrenewable resources.[2] Extraction of non-renewable resources reduces the amount left for the future, and the waste material places pressures on ecosystems.

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), opening the potential for economies based on a steady, but constrained, flow of renewable resources. Unlike mineral resources – whose total capacity is finite and whose annual production is limited by the availability and quality of mines and the equipment to extract them[3] – renewable resources can remain productive indefinitely into the future, but only as long as extraction rates do not exceed sustainable limits. Once sustainable limits are exceeded, renewable resources degrade.

It may possible for economic output to rise in monetary terms while ma-

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

[2] Energy is necessarily degraded when it is used, a conclusion that follows from thermodynamic principles. Renewable energy requires an external source, ultimately solar energy, which provides the energy for carbon fixation in plants and drives the wind, waves, and water cycles. Nonrenewable fossil fuels were formed over millennia from carbon fixed by photosynthesis in ancient plants under forces driven by the decay of radioactive materials present in the Earth's interior when it was formed. Nuclear energy relies on deposits of radioactive materials in the Earth's crust, and is also nonrenewable. Some non-biological materials can be recycled, but not fully, and recycling takes energy.

[3] This paper will spend no time debating the Hotelling rule, under which non-renewable resources would be phased down optimally over an indefinite future. It appears to have no empirical relevance, whether in explaining the behavior of mining firms or in explaining resource prices (Livernois, 2009). To be fair, 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.

terial and energy throughput declines. This is termed "absolute decoupling" and is required for economic growth to persist on a finite planet. However, in practice only relative decoupling is observed on 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, 2020). They therefore reject appeals to decoupling as a way to reconcile business as usual economic activity with life on a finite planet (Kallis, 2018). To be clear, degrowth is not recession. Rather, it is an intentional downscaling of economic activity such that everyone can enjoy a good quality of life. It implies changes in behavior, institutions, and norms compatible with that downscaling.

The degrowth literature does assume the continued availability of advanced materials and technology (Hickel, 2020; Kallis, 2020). It further assumes that innovation is required in order to meet future needs (Hickel, 2020; Kallis, 2018). More broadly, the degrowth community, which includes both researchers and activists, displays ambivalence. 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).

Yet, even "convivial technologies" (Deriu, 2015; Kallis et al., 2018, p. 304), a key plank of degrowth strategies, require upstream manufacturing to produce and maintain them.[5] Indeed, Deriu (2015, p. 81) notes that Ivan Illich,

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

[5] 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

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.

This paper starts with the claim that much of the degrowth literature, particularly on convivial technologies, implicitly or explicitly requires an industrial "core", within which technological innovation remains vital and productivity growth is expected. Certainly, a degrowing economy is likely to de-emphasize saving labor hours, and as Kallis et al. (2018) point out, this can encourage dispersed small-scale manufacturing. However, economies of scale in large-scale operations can enable efficiencies in material and energy use that are not achievable by small-scale producers. A degrowth pathway should, in the view taken in this paper, increasingly favor small-scale production compatible with convivial activity without entirely losing an organized high-efficiency manufacturing core.

Consistent with the proposed view on a degrowing economy, this paper presents a stylized dual-economy model with a convivial economy that predominates in everyday life, together with an industrial core.[6] The model in this paper is an adaptation and extension of a post-Keynesian steady-state model developed by Cahen-Fourot and Lavoie (2016). Those authors showed that a steady state with positive profits is possible if there is saving out of wealth, thus contradicting the claim of Kallis (2020, p. 47) that a fixed economic pie entails zero net profit. Their 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

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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.

[6] Strictly speaking, a convivial economy is one dominated by convivial activity, so it encompasses both the industrial core and convivial activity. For the purposes of this paper, "convivial economy" refers to that part of the economy that lies outside the industrial core.

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.

Activities in a convivial economy might respond to a variety of needs, including the pleasure of doing things oneself, social engagement, or the display of creativity. If an individual, household, or community needs materials and services from the industrial core, then it must generate some profits, but profits are not a unique or even dominant driver of behavior, and many participants may charge nothing at all. Convivial innovation can likewise be driven by multiple motivations: restless tinkering; a search for variety; adapting convivial technologies to new purposes; "scratching an itch" for a shared DIY challenge; and so on. The resulting variety of activities and motivations resists systematic analysis. The challenge is sidestepped in this paper through a key assumption: that material and energy throughput is constrained in the industrial core, while the convivial economy accesses material and energy only as embodied in products and services from the core. In this way, the operation of the convivial economy is constrained by, but isolated from, resource extraction. Waste flows are not treated explicitly, but are presumed to be substantially reduced in both the industrial core and the convivial economy through reuse, refurbishment, and recycling.

This paper contributes to the literature in several ways. First, it adds (however modestly) to the very small number of explicit macroeconomic degrowth models (Savin and van den Bergh, 2024). Second, it introduces the concept of the industrial core and suggests a way to include convivial activities in a stock-flow consistent post-Keynesian model. Third, it adds a wealth tax, which will prove to be an important innovation 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 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 degrowth 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. It begins by explaining the distinction between the convivial economy and the industrial core and how they work together. Next, it elaborates on the classical notion of the long-period position, contrasting it with the “distant future” envisaged as being the end of a degrowth pathway. It then explains the approach to profits, technological change, and innovation.

2.1. The convivial economy vs. the industrial core

As mentioned in the Introduction, the model in this paper constrains the economy to lie within biophysical limits through a collectively-imposed constraint on the industrial core’s use of the sustainable flow of resources provided by renewable resources. No biophysical constraint is applied to convivial activity because of a simplifying assumption: all resources used by the convivial economy are embodied in goods purchased from the industrial core. Any direct use of resources by the convivial economy, such as in garden allotments, is presumed to be constrained through local rules for managing a local commons. The constraint on the industrial core, which is critical when activities take place far from the source of the resource flow, is imposed by a collectivity called “government” in this paper. The government can be thought of more broadly as a set of governance arrangements through which resources are collectively managed. The key role of the government in the model is to pool, use, and distribute a subset of resources, whether in their raw form or processed by the industrial core.

The model features a one-way interaction between the industrial core and the convivial economy through demand for the products of industry by the convivial economy. Those products include durable goods such as Illich’s iconic bicycle, shop tools, and, perhaps, computers and 3-D printers. They also include materials and services such as grease for the bicycle chain, hardware and finished boards for the shop, a reliable network for the computers, and feedstock for the 3-D printers. Electricity can be provided through a grid or from off-grid production; grid power would be supplied by the industrial core, perhaps purchased by the government, while off-grid generation would use equipment supplied from the industrial core.

This structure can be compared to the illustrative model of Jackson and Victor (2011), which contains three sectors: a a conventional sector; a green infrastructure sector; and a "green services" sector. Each sector contributes to GDP. Steady-state or degrowth trajectories are achieved by reducing working hours in the conventional and green infrastructure sectors, while expanding the low-productivity green services sector, which is "based on the expansion of community based, resource light, low-carbon, service-based activities." The present paper's industrial core corresponds roughly to Jackson and Victor's conventional and green infrastructure sectors, while the convivial economy corresponds roughly to the green services sector. However, there are some important differences. First, the industrial core is expected to shrink substantially and to mainly supply a combination of essential needs and inputs to the convivial economy. Second, the convivial economy produces goods as well as services. Third, only the industrial core certainly contributes to the monetary economy.

Regarding the last point, money can change hands in the convivial economy, but it does not have to. The industrial core needs up-front finance, and therefore money as a store of wealth. In contrast, while some parts of the convivial economy may require savings – for example, to build a shop or to accumulate inventory – others will not. Where substantial savings are not required, a local currency can facilitate transactions, but transfers of goods and services could be made through other means. "Barter" is the commonly assumed alternative, to the point that it has become banal, but Graeber (2014) persuasively argues that barter is extraordinarily rare, and problematic when it appears. He argues instead that economic relations everywhere are, in addition to the modern practice of monetary exchange, a mix of: "from each according to ability, to each according to need"[7]; slightly unequal exchange in which accounts are never kept, and therefore never closed; and hierarchy, characterized by customary and unequal transfers. The convivial economy can be expected to feature a shifting mix of each modality. For this reason, the focus in this paper is on the industrial core, while allowing for at least some monetary exchange in the convivial economy.

2.2. Long-period positions vs. the distant future

Kerschner (2010) has argued that the long-run future towards which de-

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[7] He notes that, ironically, this "communist" practice prevails inside the modern firm.

growth 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 (private actors today, the "government" in the distant future).

2.3. Profits and innovation in the industrial core

Firms in the industrial core compete on the basis of profitability. While some degrowth theorists have argued that net positive profits are impossible in a degrowing economy (see, e.g., Kallis, 2020, p. 47), Cahen-Fourot and Lavoie (2016) showed that it is possible when there is consumption out of wealth. That finding, which was confirmed by later writers (Richters and Siemoneit, 2017; Hein and Jimenez, 2022), will be elaborated further in this paper and applied to a degrowth pathway.

Competition over finance based on profitability is a classical rather than a neoclassical conception of competition, although it certainly underlies main-stream theories of finance. Rather than price competition in the goods market, firms compete for financing of their planned investment in new production. Those providing the finance look to prospective future returns. Investors do not necessarily seek maximum returns, but do require a certain degree of anticipated profitability before they will commit funds. This is the essence of capitalism, and thus the industrial core in this paper is a capitalist core.

The role proposed for profits in this paper is consistent with Minsky (2008, chap. 7), who argues that profits validate debt and capital asset prices. The motivation for a competitive sector where efficiency is at a premium is that it encourages local and perhaps surprising solutions that only hands-on experience can provide, under the spur of reducing costs. But as Feola (2020) points out in the context of sustainability transition research, assuming capitalist institutions is not a neutral choice. Indeed, for degrowth theorists, an *economic* analysis is not a neutral choice (Kallis, 2018, p. 8).

The choice to proceed with a capitalist structure for the industrial core is justified through two distinct arguments. First, the central claim of this paper is that the degrowth literature implies an industrial core, but the precise form it might take is underdetermined. While this paper chooses to model it on capitalist practices, other institutional arrangements and motivations are possible. However, second, by separating ownership from management and productive activities, the modern capitalist firm has proven to be quite flexible. The institutional economist Gardiner Means called this structure "collective capitalism" (Means, 1957). He argued for "planning without compulsion," in which the government provides a framework for the effective use of resources while allowing for private decisions within that framework. As Illich's vision for a convivial economy was to disrupt the industrial monopoly on meeting needs while retaining useful industrial activity (Deriu, 2015), a capitalist industrial core dominated by convivial activity is arguably consistent with the degrowth vision. However, that holds only if industry is suitably constrained. In post-Keynesian theory, profits are a key means by which firms establish power over their environment (Lavoie, 2022, p. 133). The model presumes that institutions are in place (and likely evolving) to keep that power within bounds. The explicit mechanism introduced in this paper is a wealth tax.

2.4. Technology and innovation

There is some debate on just what “innovation” should mean in the degrowth context. de Saille and Medvecky (2016) note that the responsible innovation literature contrasts innovation with stagnation, but “stagnation” is also viewed as the opposite of “growth,” implicitly tying innovation to growth. The consequence is that degrowth is excluded from the list of responsibilities that “responsible innovation” seeks to meet. The same authors both broaden and narrow the definition of innovation, going beyond “the market” to “the public sphere,” but also requiring that innovation lead to a “profound re-ordering of what-has-been” (de Saille and Medvecky, 2016, p. 7). This paper starts instead from the definition of innovation offered by the Oslo manual (OECD and Eurostat, 2018, p. 20),

> An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit’s previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process).

The Oslo manual is a guide to data collection on innovative activities by firms, but the definition can be applied outside of that context. From this definition, it is clear that much innovative activity will not lead to a profound re-ordering. We view innovation as mostly incremental, taking place simultaneously and continually, but differently, in the convivial economy and in the industrial core.

Note that innovation need not be “environmental innovation.” In their inaugural paper for the journal *Environmental Innovation and Societal Transitions*, van den Bergh et al. (2011, p. 5) state that, “The main difference between environmental and ‘regular’ innovations is the combination of an urgent environmental problem that needs a solution but which is associated with external costs that do not enter the private costs of the polluter.” This is stated with the language of neoclassical welfare economics, but the situation applies to the non-neoclassical model in this paper. With Pirgmaier (2017), we reject market allocation as a reliable means to maintain a steady state. Instead, the external costs of unsustainable use are reduced through a transfer of resources from private to communal control. When private actors own resources, the model in this paper assumes that resources are extracted at an unsustainable rate, while under management by the model’s “government”, resource flows are kept within sustainable limits. Thus, environmental governance, rather than environmental innovation, is the key driver of change.

Under the spur of constrained resource availability, much innovation might be characterized as "environmental", but this paper does not distinguish it from the broader innovation landscape.

In practice, much innovation is of the "doing, using, and interacting" (DUI) type, as well as "science, technology, and innovation" (STI) (Lundvall, 2007, p. 104). Whether within the industrial core or the convivial economy, reasonably steady changes in productivity can be expected, even without scientific advances. Admittedly, a major transition requires patient, mission-driven, long-term public finance if private investment is to prove attractive (Mazzucato and Semieniuk, 2017). However, this paper does not examine innovation costs; in the model, the public expenditure associated with the transition is payment for resource transfers from private to communal control.

Instead, in this paper, innovation is tied to technological change driven by costs, through the mechanism of cost share-induced technological change. Cost-driven endogenous technological change has long been a feature of classical and Marxian analysis (Dutt, 2013). More recently, it has been incorporated into post-Keynesian models (Cassetti, 2003; Hein and Tarassow, 2010). Duménil and Lévy (1995, 2010) sought to provide a stronger microeconomic foundation for classical cost share-induced technological change, which they accomplished through a classical-evolutionary model. Their theory assumes that firms search in the vicinity of their current technology for candidate innovations, accepting those candidate innovations that raise the profit rate. As noted by Kemp-Benedict (2022, 2024), the profitability criterion is compatible with firms' capital budgeting processes, and thus has a sensible behavioral basis.

While Duménil and Lévy's model explains the link from cost shares to productivity growth, cost shares themselves are determined by productivities together with price and wage-setting. Thus, different model closures result in different outcomes. For example, a fixed markup can translate into a steadily declining profit rate, while other pricing procedures can lead to stable profit rates (Julius, 2005). Duménil and Lévy's model was further elaborated by Kemp-Benedict (2019, 2022, 2024), who showed that when Duménil and Lévy's model is combined with price and wage-setting behaviors, the resulting model has a long-period position characterized by constant productivity growth rates and cost shares. This general finding will be applied in this paper. Cost shares and growth rates depend on the price and wage-setting regime, while productivity levels depend on model parameters and may be path-dependent.[8]

An explicit requirement of Duménil and Lévy's model, one that is key to classical and Marxian theory and thus implicit in other theories of cost share-induced technological change, is that firms' technological choices are driven by the prospect of profits. However, firms emphatically do *not* maximize profits, because they cannot. In this model, R&D is an evolutionary process that lies upstream from capital budgeting, where "go–no-go" decisions are made. Evolutionary models are essentially process-based, and in such models agents do not maximize (Nelson, 2018, p. 15). The evolutionary process of innovation generates a cumulative advance (Dosi and Nelson, 2018), but individual firms are exploring, not optimizing, and either retaining or rejecting what they discover based on profitability.

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 communal, "government", control. 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. 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.

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[8] For example, in a cost share-induced model of technological change, the growth rate of capital productivity, $\hat{\kappa}$, will depend positively on the profit share π: $\hat{\kappa} = k(\pi)$, with $k' > 0$. (In this paper, a "hat" denotes a growth rate.) Under target-return pricing, $\pi\kappa = r^* = \text{const}$, so $\hat{\pi} + \hat{\kappa} = 0$. As a result, $\hat{\pi} = -\hat{\kappa} = -k(\pi)$. This generates a stable dynamic with an equilibrium value of the profit share π^* that satisfies $\hat{\kappa}^* = k(\pi^*) = 0$. Thus, under target-return pricing, the long-period position features a constant cost share and constant capital productivity, two of Kaldor's "stylized facts" (Kaldor, 1961). The level of the capital productivity depends on the target profit rate: $\kappa^* = r^*/\pi^*$. Under other pricing behavior (fixed markup, conflict wage pricing, and so on), the long-period position may be different.

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 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 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.

3.1.1. Transactions flow matrix

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

Net core 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 core 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. The corresponding transaction is expenditure by households and income for firms in the industrial core.

Table 1: Transactions flow matrix

	Households		Industrial Core		Gov't	Σ
	User	Producer	Current	Capital		
Net core consumption	$-C$		$+C$			0
Govt expenditure			$+G$		$-G$	0
Investment			$+I$	$-I$		0
Convivial production		$-M$	$+M$			0
Convivial exchange	$-E$	$+E$				0
[*Production*]		$[H]$	$[Y]$			
Wages	$+W$		$-W$			0
Profits	$+\Pi$		$-\Pi$			0
Resource rents	$+p_r R_h$		$-p_r R$		$+p_r R_g$	0
Depreciation			$-D$	$+D$		0
HH mixed income	$+H$	$-H$				0
Saving	$-S$			$+\Delta K$	$+\Delta B$	0
Interest	$+iB$				$-iB$	0
Resource transfers	$+A$				$-A$	0
Taxes net of transfers	$-T$				$+T$	0
Σ	0	0	0	0	0	0

Table 2: Balance sheet

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

Table 3: Revaluation matrix

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

Govt expenditure & Investment

The government also purchases from the industrial core (and, as a simplifying assumption, *not* from the convivial economy), a transaction recorded under "Govt expenditure." This expenditure at a minimum supports decent living standards through public infrastructure provision and maintenance and support for caring activities. 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.

Convivial production & Convivial exchange

The next two rows reflect the *monetary* component of the convivial 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, "Convivial production" records the purchases of goods and services from the industrial core that are used by households for convivial production. 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 industrial core. The "Convivial 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 industrial core, denoted by Y, is equal to sales of consumption goods, goods purchased by government, investment goods, and intermediate goods for household convivial production. The equivalent income expression is the sum of wages W, profits Π, and rents $p_r R$, net of depreciation D. The difference between income and expenditure for monetized convivial production, $E - M$, is denoted by H. It represents value added in the monetized part of the convivial economy.

Wages & Profits

Households receive both wages and (net) profits from firms in 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 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.

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). 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 resource commons. 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. As with other one-sector models, the economy produces a homogeneous final good (or an aggregate, "vertically integrated", good for which a suitable price index has been constructed). That good is used indiscriminately for household consumption, government expenditure, and investment. However, resource flows cannot be equated to the homogeneous final good, and must be given a price. The price of the homogeneous final good provides a *numéraire*, while the resource price p_r is a real price relative to the *numéraire*.

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 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 government (and not in the opposite direction), and are recorded in a separate row.

Interest

The government pays interest on bonds at a rate i, an assumption also made by Cahen-Fourot and Lavoie (2016).

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.

Taxes net of transfers

In the model, taxes are assessed on households alone. They represent expenditure for households and income for government. 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 government purchases of resources. They also derive income from convivial activities. The model assumes that all core income is taxed at the same rate, τ, while convivial activities are not taxed. Furthermore, the model allows for a wealth tax at a rate τ_v,

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

The assumption that convivial activities are not taxed is not essential to the model. However, taxing convivial activities would add to the model's complexity without providing insight into the focus of this paper, the role of the industrial core.

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 household (convivial) production, leaving only Y. This could be called GDP_1:

$$\mathrm{GDP}_1 = Y. \tag{2}$$

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

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

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

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

Along the degrowth pathway presented later in this paper, GDP_1 almost certainly exhibits degrowth. To the extent that much economic activity moves into the non-monetary economy, it likely that GDP_2 will also degrow. However, 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 convivial 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 industrial core, Y, or GDP_1. The key distinction for sustainability is that the industrial core is where natural resources are used in their raw form, while the convivial economy only uses resources indirectly, as embodied in products and services purchased from the industrial core.

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.[9] 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 collective ownership 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

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[9] 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).

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 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 is denoted by κ, labor productivity by λ, and resource productivity by ν. Output from the industrial core is given by the most constrained input:

$$Y = \min\left(\kappa K, \lambda L, \nu R\right). \tag{9}$$

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,

$$Y = \kappa K = \lambda L = \nu R. \tag{10}$$

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 $\underline{R}$. This paper assumes that the total flow R satisfies $\underline{R} \leq R \leq \overline{R}$. Note that the envisaged sustainable flow $\underline{R}$ is 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, despite uncertainties, 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.

3.3. Saving

Households make net purchases of goods and services for their own consumption from the industrial core. 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 the convivial economy. Producers in the convivial economy make use of industrial goods, recorded as M in Table 1. However, across all households convivial exchange cancels out, $+E - E = 0$. Taken as a whole, household net purchases are from the industrial 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, a saving rate s_p from after-tax profits and interest, net of the tax on wealth, and a consumption rate c_v on wealth. The household expenditure balance can therefore be written

$$\begin{aligned} C + M = (1-\tau)W + (1-s_p)(1-\tau)\left(\Pi + iB + p_r R_h + A\right) \\ - (1-s_p)\tau_v\Omega + c_v\Omega. \quad (11)\end{aligned}$$

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

$$C + M = W + \Pi - T - S + iB + p_r R_h + A, \tag{12}$$

and combining Eqs. (1), (11), and (12) gives an expression for household saving,

$$S = s_p(1-\tau)\left(\Pi + iB + p_r R_h + A\right) - \left(c_v + \tau_v s_p\right)\left(K + B + N_h\right). \tag{13}$$

The relative size of the coefficients on the two terms in Eq. (13) is important for the steady-state. To show this, we define a new composite parameter

$$\theta \equiv \frac{c_v + \tau_v s_p}{s_p(1-\tau)} = \frac{c_v}{s_p(1-\tau)} + \frac{\tau_v}{1-\tau}. \tag{14}$$

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.[10] We now reproduce this result.

In terms of θ, the saving equation can be written

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

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 $p_r R_h = p_r \overline{R}_h = i N_h^{\text{fund}}$ and $N_h = q N_h^{\text{fund}}$, so

$$S = s_p(1-\tau)\left[(r-\theta)\,K + (i-\theta)\,B + (i-q\theta)\,N_h^{\text{fund}} + A\right]. \tag{16}$$

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.(16) becomes

$$S = s_p(1-\tau)\left[(r-\theta)\,K + (i-\theta)\,B + (i-\theta)\,N_h\right]. \tag{17}$$

Bonds have zero risk – they will be paid as long as the government endures – while investment in the industrial core is risky. For that reason, a precondition for investment in firms is that $r > i$. Examining Eq. (17), 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 typical conditions, case (a) would hold, meaning that zero savings would not be possible in the US.

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[10] 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.

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. (14) 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 paramter 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, the government buys 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, while 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 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

$$A = \frac{p_{r0}}{i_0}\Delta\overline{R}. \tag{18}$$

The realized values of q, p_r, and i that prevail in private markets may diverge from those used by the government 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 government hands. In contrast to private owners, the government manages resources in a sustainable manner, so at the end of the transition, $R_h = 0$, $R_g = \underline{R}$. Along the degrowth pathway,

$$\Delta R_h = -\Delta\overline{R}, \tag{19a}$$

$$\Delta R_g < +\Delta\overline{R}. \tag{19b}$$

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,

$$\Delta\overline{R} = \frac{\overline{R}}{t_{\text{DG}}} \quad \Rightarrow \quad A = \frac{p_{r0}\overline{R}}{i t_{\text{DG}}}, \tag{20}$$

and at time t,

$$R_h = \left(1 - \frac{t}{t_{\text{DG}}}\right)\overline{R}, \tag{21a}$$

$$R_g = \frac{t}{t_{\text{DG}}}\underline{R}, \tag{21b}$$

$$R = R_h + R_g = \overline{R} - \frac{t}{t_{\text{DG}}}\left(\overline{R} - \underline{R}\right). \tag{21c}$$

The growth rate of resource use is

$$\hat{R} = \frac{\dot{R}}{R} = -\frac{\overline{R} - \underline{R}}{t_{\text{DG}}\overline{R} - t\left(\overline{R} - \underline{R}\right)}. \tag{22}$$

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 ultimately implausible closure, in which everything works out "just right", followed by a discussion of possible extensions to achieve a more realistic closure.

4.1. Goldilocks degrowth path

The explicit closure can be thought of as a just-right or "goldilocks" degrowth path. The purpose of the goldilocks path is not realism, but to determine minimal requirements for a degrowth pathway and to provide a benchmark for discussing alternatives. Along a goldilocks path, everything changes in such a way that p_r, i, and q do not change. This outcome requires a degree of coordination that is extremely unlikely to occur spontaneously, to the point of impossibility. Moreover, with the best will in the world from all concerned, it is unlikely even to happen by design. There must be some coordinating mechanism that allows for decentralized decision-making, a topic taken up below in the alternative degrowth closure.

To keep the resource price stable, output declines at the same rate as resources. With no pressure on resources, cost shares and prices are stable, and we can assume that $\hat{\kappa}=\hat{\nu}=0$. When these conditions hold,

$$\hat{Y}=\hat{K}=\hat{R}=\hat{\lambda}+\hat{L}, \tag{23}$$

where the growth rate of labor productivity, $\hat{\lambda}$, is at prevailing rates. Note that because $\hat{R}<0$, the capital stock is declining, as is production from the industrial core. This is indisputably a degrowth path.

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.

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,

$$K=K_0\left(1-\frac{t}{t_{\mathrm{DG}}}\sigma\right). \tag{24}$$

The total volume of bonds B is assumed not to change. With this assumption, 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. (13) shows that

$$\begin{aligned} -K_0\frac{\sigma}{t_{\mathrm{DG}}}\delta =& s_p(1-\tau)\left[rK_0\left(1-\frac{\sigma t}{t_{\mathrm{DG}}}\right)+i_0B_0+p_{r0}\overline{R}\left(1-\frac{t}{t_{\mathrm{DG}}}\right)\right] \\ &-(c_v+\tau_v s_p)\left[K_0\left(1-\frac{\sigma t}{t_{\mathrm{DG}}}\right)+B_0+\frac{p_{r0}}{i_0}\overline{R}\left(1-\frac{t}{t_{\mathrm{DG}}}\right)\right] \\ &+s_p(1-\tau)\frac{p_{r0}}{i_0}\frac{\overline{R}}{t_{\mathrm{DG}}}\delta. \end{aligned} \tag{25}$$

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

$$\delta = \begin{cases} 1, & t \in [0, t_{\mathrm{DG}}], \\ 0, & t \notin [0, t_{\mathrm{DG}}]. \end{cases} \tag{26}$$

Eq. (25) 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

$$\frac{p_{r0}\overline{R}}{K_0} = \rho\kappa, \tag{27}$$

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 goldilocks pathway ρ and κ do not change. Furthermore, defining β_0 as the initial ratio of government debt to industrial core output, B_0/Y, the ratio of government debt to the initial capital stock is

$$\frac{B_0}{K_0} = \beta_0\kappa. \tag{28}$$

With these definitions, and dividing Eq. (25) through by K_0 gives

$$\begin{aligned} -\frac{\sigma}{t_{\mathrm{DG}}}\delta = & s_p(1-\tau)\left[r\left(1-\frac{t\sigma}{t_{\mathrm{DG}}}\right)+i_0\beta_0\kappa+\left(1-\frac{t}{t_{\mathrm{DG}}}\right)\rho\kappa+\frac{\rho\kappa}{i_0 t_{\mathrm{DG}}}\delta\right] \\ &-(c_v+\tau_v s_p)\left[\left(1-\frac{t\sigma}{t_{\mathrm{DG}}}\right)+\beta_0\kappa+\left(1-\frac{t}{t_{\mathrm{DG}}}\right)\frac{\rho\kappa}{i_0}\right]. \end{aligned} \tag{29}$$

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.

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

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 ($\delta = 0$).

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

$$t_{\mathrm{DG}} > \frac{1}{c_v + \tau_v s_p}\frac{\sigma}{1 - \sigma + \beta_0\kappa}. \tag{30}$$

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 $\kappa = 0.25/\text{year}$, 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 $c_v = 0.01/\text{year}$ 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 $c_v + \tau_v s_p = 0.05/\text{year}$, then the minimum duration shrinks to about two decades.

4.2. More realistic degrowth paths

As noted earlier, the goldilocks path is not a realistic pathway, even if a degrowth policy became 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). But setting that aside for now and assuming that a degrowth policy is widely accepted, 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 close. That can be achieved in principle through government regulation (e.g., closing inefficient plants) or through government purchases. However, it can also be achieved through price competition over the smaller amount of resources. If the latter, then as government buys resources and restricts production to sustainable levels, p_r can be expected to rise. Even though the government is 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.

A further alternative is that the government 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 government 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.

If the resource price p_r rises due to competition, the resource cost share $\rho = p_r/\nu$ also rises. From cost share-induced technological change, that will drive 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.

Note that regardless of the change in resource productivity, this model features 100% rebound. Any increase in efficiency immediately translates into increased output if the resources are available. The government-imposed constraint on resource use is therefore crucial. If cost share-induced technological change leads to a rise in ν, then resource-constrained output from the industrial core, equal to $\nu\underline{R}$, will be higher than along the goldilocks path, although it may well be below the initial output, reflecting degrowth.

To the extent that a rising resource cost share lessens the profit and wage shares, capital productivity could decline, labor productivity grow more slowly than before the transition, or both. This means that the capital stock, employment, or both will be higher than along the goldilocks path. Despite these changes, the result is likely to be a degrowth path due to biophysical constraints on lowering ν.

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. That core can (although perhaps need not) be treated with analytical tools developed for capitalist economies. That leaves the problem of how to treat convivial activity itself, a problem that is dealt with in this paper 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.

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 the model's "government." The transfer is made through eminent domain following a fair compensation principle. The government is assumed to restrict resource flows to a sustainable yield that takes into account 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 degrowth.

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 government. 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 "goldilocks" pathway, in which purchases of resources by the government 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 might 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.

One crucial issue has been entirely avoided in this paper: 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. A further issue has been side-stepped through an assumption: that waste streams are minimized through circular economy practices. An explicit treatment of wastes could follow the path laid by Dafermos et al. (2017). These topics are left to further work.

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 model of a mixed convivial-industrial economy that allows for a treatment of a degrowth path between an industrial-dominated to a convivial-dominated economy.

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. Hein and Jimenez (2022) showed moreover that consumption out of wealth must be sufficiently high, a finding 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 an ideal 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.

A further feature of the model presented in this paper is that the steady-state economy at the end of a degrowth pathway is not unique. It depends on the particular path followed. In particular, it depends on how resource prices respond to changing resource availability and how interest rates on government debt respond to the government's financing of the transition.

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 possibility for path-dependent behavior and demonstrates the need for consumption out of wealth, a wealth tax, or both, for degrowth to be possible.

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