



ARTICLE




<https://doi.org/10.1057/s41599-024-02993-8>

OPEN

Ecological money and finance—upscaling local complementary currencies

Thomas Lagoarde-Ségot¹   & Alban Mathieu²

This paper puts forth a new pathway to sustainable policy to upscale the transformative power of local complementary currencies. It first reviews the mechanisms by which complementary currencies re-embed monetary circulation within sustainability and biomimetic resilience criteria. It then puts forth a prototype policy pathway whereby private banks swap SDG impact certificates of their complementary currency loans against new reserve assets held at the Central Bank. It finally provides analytical insight on this prototype policy with a new PK-SFC model comprising 106 accounting and behavioral equations. Simulations show that the prototype policy generates short-lived economic expansion, increases banking stability, and induces structural change through increased systemic capacity for evolution, resilience, and fitness for evolution. We finally discuss the practical implications of our results for sustainability policies.

¹KEDGE BS and SDSN France, Bordeaux, France. ²KEDGE BS, Bordeaux, France. email: thomas.lagoardesegot@kedgebs.com

Introduction

Multilateral development banks have recently committed to “developing, testing, and expanding the use of innovative instruments to support nature positive investment” (Multilateral Development Banks 2021). The UN Secretary General has also called for “innovative approaches, bold policy decisions, and new sources of funding” (UN 2023) to “aggressively scale up sustainable development goals (SDG) financing” (UN 2023). This paper contributes to these objectives by putting forth a policy prototype to upscale the transformative power of local complementary currencies (LCCs).

LCCs consist in monetary token, backed up by a guarantee fund in the legal tender, and used to exchange goods and services within a specific community. Several studies have highlighted LCC’s contribution to sustainability (Lietaer et al. 2010; Escobar et al. 2020; Aglietta 2018; Ansart and Monvoisin 2017; Blanc 2018; Blanc and Lakócai 2020). Yet, the consensus is that LCCs should be integrated into public policies to induce structural change (Blanc 2020, 2022; Cauvet and Perrissin Fabert 2018; Aglietta and Espagne 2016).

We thus put forth a simple mechanism to endogenize the creation and destruction of LCCs deposits in the economy. New LCC deposits would be created though new bank loans and destroyed with the payment of taxes or the reimbursement of loans. This would disconnect the supply of LCCs from the ‘deposit guarantee fund’ and maintain their value through a full integration into the monetary system. Banks would then swap LCC loan impact ratings against new reserve assets at the Central Bank, which would apply a discretionary haircut rate. To mitigate moral hazard, the proposed setting also envisages a clear separation of mandates and responsibilities across stakeholders. This prototype policy would contribute to the SDGs by supplying rapid finance for sustainable public goods, and by harnessing the circulation properties of LCCs. It could thus open a new sustainable policy pathway.

Following Lucarelli and Gobbi (2016), we provide analytical insight using a simple new stock-flow consistent (SFC) model of 106 equations. This model also contributes to the ecological SFC modeling literature by including new metrics for total capacity for development, resilience and fitness for evolution (Ulanowicz et al. 2009).

In our simulations, the prototype policy increases the circulation of LCC and exerts an expansionary effect on the economy. Incremental GDP growth is fueled by new LCC loans that bridge the finance gap for social businesses. This in turn generates LCC investment and consumption spending, and LCC profits. The policy also appears to induce structural change, as shown by increased capacity for development, resilience, and fitness for evolution. Finally, simulations report increased financial stability, banking sector profits, and household savings diversification.

The remainder of this paper is structured as follows. Section 2 briefly reviews the literature on LCC schemes and sustainability. Section 3 outlines and discusses our prototype monetary policy mechanism. Section 4 presents the model’s transaction matrix and its behavioral equations. Section 5 analyzes our simulations. Section 6 outlines our conclusions and discusses their practical implications.

Local complementary currencies

Delineating local complementary currencies (LCCs). Alternative currencies are monetary devices created by non-banking actors in order to trigger a socio-economic transformation. These monetary innovations are diverse in terms of their organization, relationship with the monetary system, and purpose. As opposed to banking deposits, they are not issued by governments (though

deficit spending), nor by banks (through credit), but by a business or by an association. A wide range of alternative currencies have developed in recent years, such as cryptocurrencies (e.g. Bitcoin), business to business to mutual credit (e.g. Sardex), inconvertible local currencies (e.g. Ithaca Hour), convertible local currency (e.g. Palmas), general mutual credit (e.g. LETS), mutual credit between individuals based on times-based services (e.g. Time banks), or green practices reward schemes (e.g. NU spaarpas). Within this classification, local complementary currencies (LCCs) share a set of specific attributes (Table 1).

LCCs are complementary, rather than alternative, given that they do not challenge the modern monetary order, but extend it, by giving money new purpose-driven objectives such as solidarity, sharing, reciprocity, and environmental protection (Blanc 2011, 2017; Didier 2022).

LCCs are initiatives of citizens seeking to re-embed money within the logic of the commons. LCCs are issued by associations of citizens wishing to use money for a given purpose, which can be economic (e.g. supporting local businesses), social (e.g. promoting social and ecological values in the economy), or territorial (e.g. building to sustainable communities) (Fare and Ould Ahmed 2017). LCC communities usually favor a sociocratic governance, i.e. “a mode of governance and decision-making that allows an organization to behave like a living organism, that is, to self-organize” (Buck and Endenburg 2004).

LCC participants cannot be qualified as pure utility-maximizing money users, but instead as local monetary community members (Blanc 2018). LCC transactions indeed involve strong ties of reciprocity, transparency, fairness and solidarity (Blanc 2017, 2022). The socioeconomic literature thus characterizes LCCs as social innovations that seek to re-embed—in the Polanyian sense—economic exchange within shared ecological and social criteria (Richez-Battesti et al. 2012; Polanyi 2009).

LCCs are fully convertible into legal tender. Convertibility is typically guaranteed by a one-to-one matching between each unit of LCC and previous legal tender banking deposits (held by LCC users, most often in a social economy bank or a mutual bank)¹. From a financial perspective, holding LCCs is thus akin to holding cash or sight deposits in legal tender (with or without demurrage).

Finally, LCCs self-identify their own socio-economic and spatial limits in order to fulfil their ecological and social agenda (Blanc 2022, pp. 14–19).

More than 4000 LCCs have been developed in more than 50 countries since 1990 (Carrillo 2018). However, LCCs are diverse and evolve over time. According to Blanc (2011 8), “each generation [of CCs] included a series of experiences often related to each other, while each generation entertains links with experiences from previous ones and provides models, positive or negative, for futures ones”. Four generations of LCCs have been identified in the literature. First and second generations LCC schemes, take the

Table 1 Characteristics of local complementary currencies (LCCs).

On:	LCCs
Ideology	Commons
Governance	Sociocratic
Transaction type	Community members
Unit of account	Complete
Store of value	Liquid asset
Medium of exchange	Incomplete
Conception of money	Social bond

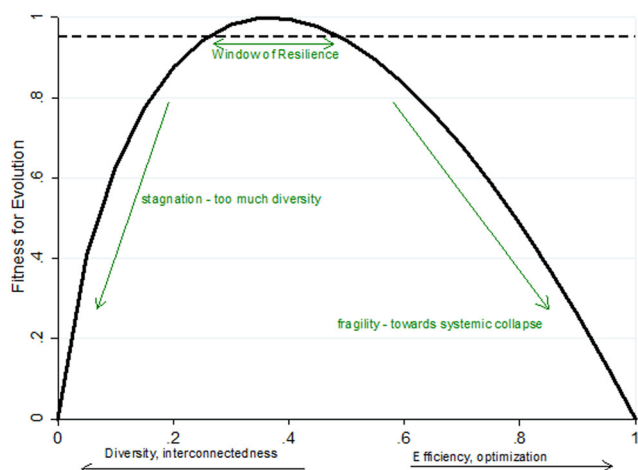


Fig. 1 Fitness for evolution and resilience. Note: this graph represents the ability of the system to evolve $F = -\log(a)$ for different values of $0 < a < 1$. The dotted line indicates values above 0.954 and the resilience window. See Ulanowicz et al. (2009), for more details.

form of mutual credit systems (e.g. LETS) and time exchange schemes, respectively, and emerged in the early 1980s. Third generation schemes, beginning with Ithaca in 1999, gave rise to LCCs as they are known today. Fourth generation schemes, which have been implemented since 2002–2003, include local governments as stakeholders, often in the context of sustainability policies.

All LCC schemes contribute to sustainability by developing an ecological awareness, by reorienting household consumption accordingly, and by promoting solidarity and social ties (García-Corral et al. 2020; Magnen and Fourel 2015; Lung 2022; Lafuente-Sampietro 2023; Fois Duclerc and Lafuente-Sampietro 2023).

LCCs and sustainability in a biomimicry perspective. According to Lietaer et al. (2012), the monetary system is merely one subsystem of the economy, which is itself a subset of society and the environment; and no subsystem can function effectively unless it is in harmony with that wider entity. According to cybernetics, natural, economic and monetary and systems rely on transfers between actors and their fitness for evolution depends on a trade-off between *throughput efficiency* and *resilience* (Ulanowicz et al. 2009; Lietaer et al. 2010)².

In an economy, the catalysing medium (money) should thus circulate amongst all corners, flow through all forms of organization (charity, limited liability company—LLC, public limited company—PLC, cooperative, mixed association, small and medium-sized enterprises (SMEs), etc.) and allow for various forms of exchange to take place (including gift, reciprocity, non-market exchange, and market exchange) (Lagoarde-Segot and Paraque 2018).

The fitness for evolution curve (F) observed in natural ecosystems is shown in Fig. 1 and highlights a trade-off between diversity and efficiency/optimization. Excessive diversity (e.g. too many species) leads the system to stagnate, and excessive throughput efficiency (e.g. each predator matches a single abundant prey) increases the risk of systemic collapse (e.g. if the single prey disappears). The ‘natural window of resilience’, where $F > 0.95$, requires more diversity than efficiency³.

Note that fitness for evolution can take on significantly different values for the same level of throughput. For a given GDP, a lack of interconnectivity may create a stranglehold undermining resilience and fitness for evolution. Excessive money concentration, and insufficient connectiveness weakens the system’s ability to absorb unexpected shocks. The purpose of LCC schemes being to increase monetary circulation where it is

the most needed, one may expect their development to be conducive to improved resilience, fitness for evolution, and sustainability.

Linking LCCs and public policies

Literature review. Policy interest in LCCs can be traced back to Gesell (1929) and the infamous 1930’s Wörgl experiment. It experienced a revival in the early 21st century, in the wake of success stories (such as the Swiss WIR or the Italian Sardex) (see Lucarelli and Gobbi 2016). Many policy proposals have emerged in recent years to upscale the sustainability potential of complementary currencies.

One of the most notorious was perhaps Greek Finance Minister Yanis Varoufakis’ plan for Greek complementary fiscal currencies in case of a Grexit during the 2012 Eurozone sovereign (Varoufakis 2017). Drawing on Cuban experiences with monetary dualism (Théret and Marques-Pereira 2007) and Argentinean provincial currency (Zanabria and Théret 2007), Varoufakis envisioned the creation of complementary fiscal currencies taking the form of Treasury-bills issued by the government in payment for civil servants’ salaries, pensions, and benefits. These Treasury Bills were to be convertible at par with the euro throughout their maturity, and not exchangeable outside of Greece (nor within the banking system). The Greek government, however, would accept it in payment of taxes. The macroeconomic objectives targeted through this policy were to include economic growth and reduced twin deficits (Théret 2012, 2015; Coutrot and Théret 2019a, b).

Another frequently discussed policy proposal consists in the issuing of LCCs to remedy auction failures (Fantacci 2005, 2008; Amato and Fantacci 2016). During bankruptcies, insolvent firms must indeed liquidate their assets through an auction process to pay off their creditors. During this auction, potential buyers have a considerable bargaining power over firms in financial distress. This, in turn, depresses prices and increases systemic risk (creditors being exposed to a drop in asset value). To remedy this problem, Amato and Fantacci (2016) called for introducing a complementary currency (the *com.mons*), which creditor firms would book as an asset and debtor firms as a liability. *Com.mons* issues would cover the value of the defaulted credits, following an independent evaluation of the debtor’s assets, and would be traded through a clearinghouse⁴. This would allow creditor firms to recover liquidity more easily during bankruptcies⁵, increase the negotiation power insolvent firms’ during auction, and enhance financial stability.

Other authors suggest formally tying LCC communities with monetary authorities in the framework of territorial level SDG strategies (Blanc and Perrissin Fabert 2016; Blanc 2020, 2022). These authors frequently note that the legal requirement to back up LCC issues with a reserve fund, although necessary to lock-up their value, tends to hinder the development of LCC communities (Blanc and Fare 2016; Rosa and Stodder 2015).

To remedy for this, Blanc and Perrissin Fabert (2016) suggested that LCC communities issue new LCCs for firms that undertake ecological projects. The value of these LCC issues would be backed by CO2 reduction certificates issued by a reliable third party. Local governments would then accept LCCs in payment of taxes. The new LCC deposits hence created should generate ripple effects of income and spending. This paper contributes to this literature by proposing a new policy prototype along similar lines.

A prototype policy mechanism

The basic idea. In the modern economy, money creation typically involves four balance sheet entries: a new deposit is recorded as an asset for the borrower and as a liability for the bank. It is

matched by a debt instrument which the bank accumulates as an asset, and which the borrower records as a liability. These deposits are destroyed when agents reimburse their bank loans or pay taxes to the government. For the payment system to function properly, these deposits are convertible into reserve assets at the Central Bank, which accommodates the banking system’s demand for excess reserves in its role of lender in last resort. This endogenous cycle of monetary influx, circulation and reflux, driven by banks’ and entrepreneurs’ bets, constitutes the economy’s lifeblood (Graziani 2003; Ehnts 2017).

By contrast, LCCs are akin to ‘loanable funds’ backed up by existing legal tender deposits. The proposed policy thus seeks to integrate LCCs into the monetary system. Just like euro deposits, new LCC deposits would be created (and destroyed) through the issuance (and reimbursement) of bank loans. To ensure a proper integration of LCCs they should also be convertible into Central Bank’s reserve assets.

To rapidly scale up SDG financing and ensure accountability at all levels, we propose a new monetary policy mechanism inspired by *rediscounting* (a tool often used by Central Banks to align the provision of credit with specific policy objectives (US Federal Reserve 1942; Leclercq 1982)). The Central Bank would rediscount LCC loans, based on their ex-post contribution to the SDG agenda, using monetized impact ratings carried out by an independent agency. The Central Bank maintains control over the supply of reserve issued through this process by applying a discretionary haircut rate.

These transactions would lead the Central Bank to accumulate ex-post impact certificates on its balance sheets. These non-tradeable assets would quantify the Central Bank’s contribution to the SDGs, in line with its mandate⁶. Finally, all debts and settlement instruments used in these transactions would be labeled in the legal tender, to ensure that LCCs do not spread to the interbank and financial markets.

A more precise description. The prototype policy mechanism would thus involve three main steps:

1. Private banks issue LCC loans in response to credit demand emanating from social businesses. Borrowing firms must be LCC community-members, and the funded investment project must contribute to the LCC objectives.
2. Banks accept cash, deposits in legal tender, and LCCs in payment for all loans that are due to them. The Treasury also accepts LCCs in payment for taxes. Banks operate a conversion desk, through which households can switch their euros deposits into LCCs accounts, and vice-versa⁷.
3. Impact rating agencies compute the social return on investment (SROI) of the stock of LCC deposits issued through banking loans at the previous period ($L_{s,lc-1}$), and issues corresponding impact certificates, which banks book as asset in their balance sheets. These certificates cannot be traded in secondary markets. Their nominal value (φ) is given by Eq. (1):

$$\varphi = (1 + SROI)L_{s,lc-1} \tag{1}$$

3. Banks turn to the Central Bank and swap these impact certificates for new reserve assets. The Central Bank rediscounts a fraction (τ) of these impact certificates, which it accumulates in its balance sheet. Letting ΔA be the flow of reserve deposits credited to the banking sector, and τ be the haircut used by the Central Bank, the amount of reserve assets created through this process is given by Eq. (2). By adjusting τ , the Central Bank keeps control over the supply of reserves, in line with its monetary policy objectives.

$$\Delta A = \tau \cdot \varphi \tag{2}$$

Figure 2 illustrates the above mechanism with a simple flow diagram. LCC member firms obtain a flow of loans from the

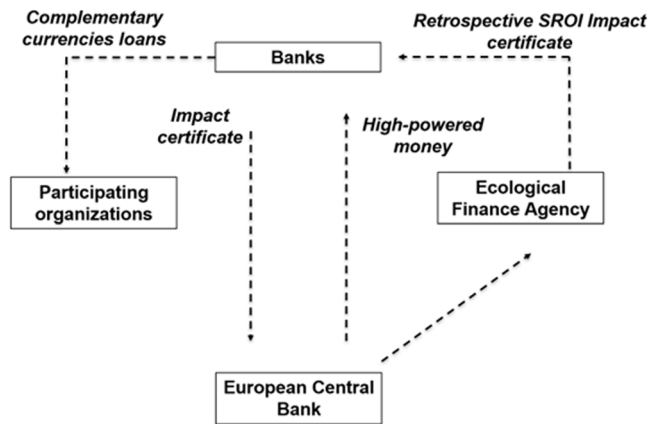


Fig. 2 A flow chart representation.

banking sector to undertake SDG contributing investments. Impact rating agencies monitoring the ex-post SROI of these loans issue new impact certificates. Finally, banks swap these impact certificates against new reserve deposits at the Central Bank.

Just like legal tender deposits, LCC deposits are hence created through bank credit, and destroyed when loans are repaid. This mechanism thus endogenizes LCCs. The demand for LCCs depends on social businesses’ demand for loans, and the supply of LCCs depends on banks’ expectations regarding SDG impact - with independent impact ratings, in conjunction with the Central Bank’s discretionary haircut policy, influencing decisions and expectations in the background.

This policy would modify the channels by which Central Banks supply reserves to the banking sector. Indeed, the current collateral system is *forward-looking*, and *cash-flow based*. As the Central Bank wants to operate risk-free, it adjusts the collateral haircut rate by assessing the solvability of the underlying borrower (for instance, the applied haircut is usually lower for sovereign bonds than for corporate bonds).

By contrast, the prototype policy introduces a *backward-looking* and *impact-based* procedure, whereby the Central Bank rewards the independently assessed, ex-post impact of LCC loans by crediting banks with new reserve. Banks are thus strongly incentivized to thoroughly screen loan applications for SDG impact to secure access to liquid reserve assets.

Governance issues. The policy mechanism generates several governance concerns. The first concern has to do with the fear that developing SDG monetized impact ratings would imply excessive commodification and financialization of nature, in opposition to the values held by LCC communities. Note however that SDG impact ratings would use the *language* of money to coordinate human activities, without implying the actual creation of markets. They would be akin to the *shadow prices* used by international organizations and social security systems to determine social opportunity costs in cases where markets do not exist or give wrong signals (Drèze and Stern, 1988)^{8,9}.

A second concern has to do with difficulties in estimating the ‘true’ monetary value of SDG-related externalities. This legitimate concern, however, applies to all financial markets, as asset prices result from mere *conventions* of judgement amongst market participants. Investing based on a hypothetical ‘fundamental’ asset value often leads to market losses (Bourghelle 2023; Chambost et al. 2019). By contrast, monetized impact ratings, which are built on a participative method and with the active engagement of all stakeholders, might provide a better picture of fundamental value that most financial market transactions (which only involve the bid and ask sides of the deal) (UK Cabinet Office 2012).

A third concern relates to risks of ratings manipulation and greenwashing¹⁰. We should first note that public impact ratings would improve the transparency of monetary policy and the accountability of Central Banks (in comparison to the present situation in which Central Banks adopt in-house, undisclosed, rating system when assessing the risk of various collaterals supplied by banks borrowing reserves). However, we agree that a strong governance structure must be put in place around these new policies to mitigate moral hazard. To prevent abuse, we suggest establishing a system of checks and balances through a clear separation of mandates, as follows:

- (i) The mandate to define impact shall be attributed to parliaments, governments, and LCC communities through a democratic institutional process;
- (ii) The mandate to measure impact shall be attributed to new multilateral impact ratings institutions, for instance by relying on the United Nations;
- (iii) The mandate to value impact (that is to turn impact into reserves) shall be attributed to national Central Bank, setting the rediscounting rate in line with their sustainability mandates and other monetary policy objectives.

A fourth concern relates to fears that the prototype policy would entail too radical a change in banking systems. We should first note that this policy would not put an end to Central Bank independence. It is a tool that may help independent Central Banks' hit their mandates to sustainability objectives. It might also be worth outlining that all economic systems, and free markets in particular, are inscribed a set of transient social, cultural, relational, and political rules, which evolve over time with policies, interpersonal relations, and cultural representations (Le Velly 2002; Granovetter 1973; Polanyi 2009). This observation holds for monetary system too, as shown by the outstanding diversity of monetary policy frameworks across time and space (Fig. 3).

Insight from a simple PK-SFC model

This section yields analytical insight into the above strategy with a new Post-Keynesian Stock-Flow Consistent (PK-SFC) model in the spirit of Godley and Lavoie (2012)¹¹. The model is comprised of 106 accounting and behavioral equations interlocked in a sectoral transaction matrix, as well as one 'hidden' equation implied by all the other. The model contributes to the SFC

modeling literature by including local complementary currencies and new resilience metrics.

The transaction flows matrix. The model's transaction matrix is shown in Table 2. This transaction matrix ensures that all flows and stock readjustment are interlocked in a watertight accounting structure, while integrating the real and financial sides of the economy. The matrix describes a simplified economy with five institutional sectors: households, production firms (divided into the LCC and the euro sector), a banking sector and a Central Bank. There is no government nor public sector in the model. This assumption means that money is emitted through bank loans (in the form of new deposits).

Each economic transaction is double-sided: one sector's income is another sector's spending, and one sector's asset is another sector's liability. Annual change to the stock of assets and liabilities held by each sector (columns) result from the budget constraint of each individual sector, defined by annual flows of income and spending (rows). This approach ensures a full integration of the real and financial sides of the economy. Following SFC modelling convention, a (+) sign indicates a source of funds while a (-) sign indicates a use of funds.

Column 1 shows the budget constraint of households. Households receive income as wages (W), profits redistributed by firms (F) and banks (FB), and interests on their euro ($r_{d,m(-1)}M_{h,m,s(-1)}$) and local complementary currency deposits ($r_{d,lcc(-1)}M_{h,lcc,s(-1)}$). Households spend their income on consumption expenditures in euros (C_m) and in complementary currency (C_{lcc}). At the end of each period, excess of income over spending accumulates in stocks of banking deposits, which households hold both in euros (ΔM_m) and in local complementary currency units (ΔM_{lcc}).

Columns 2 and 3 divide the production firm sector's transactions into a current and capital account. It amalgamates the LCC eligible sector (where both euros and LCCs can circulate) and the non-eligible sector (where only the euro can circulate). Column 2 shows the receipts and outlays of production firms. Firms receive payment flows on their sales of final goods in euros (C_m) and in local complementary currencies (C_{lcc}), as well as their sales of capital goods (in euros (I) and in local complementary currencies (I_{lcc})). Firms pay wages to households (W) (in euros and LCCs) and interest on their loans in euros ($r_{l,m(-1)}L_{m,-1}$) and in local complementary currencies ($r_{l,lcc(-1)}L_{lcc,-1}$) and set aside

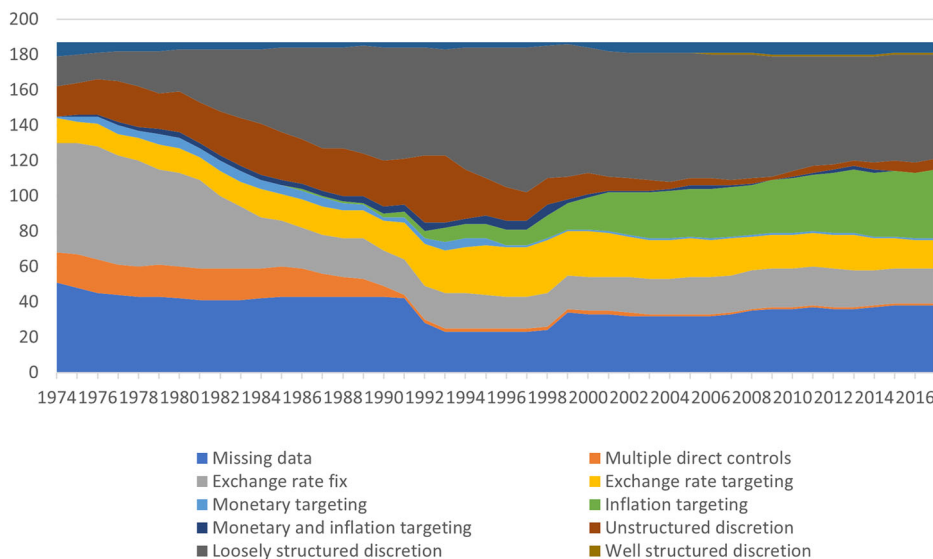


Fig. 3 Monetary policy frameworks in 187 countries, 1974–2017. Source: Cobham (2023).

Table 2 The accounting transactions flows matrix.

Transactions	Households	Production firms		Banks		Central Bank
	(1)	Current (2)	Capital (3)	Current (4)	Capital (5)	
Consumption	-C	$C_m + C_{lcc}$				
Investment		I_m	$-I_m - I_{lcc}$			
[GDP] (memo)		$+I_{lcc}$				
Wages	$W_m + W_{lcc}$	$-W_m - W_{lcc}$				
Depreciation allowances		$-DA_m - DA_{lcc}$	+DA			
Interest on loans		$-r_{l,m,-1}L_{m,-1}$		$r_{l,m,-1}L_{m,-1}$		
		$-r_{l,lcc,-1}L_{lcc,-1}$		$+r_{l,lcc,-1}L_{lcc,-1}$		
Interest on deposits	$r_{d,m,-1}M_{h,m,s,-1}$			$-r_{d,m,-1}M_{h,m,s,-1}$		
	$+r_{d,lcc,-1}M_{h,lcc,s,-1}$			$-r_{d,lcc,-1}M_{h,lcc,s,-1}$		
Changes in loans			$\Delta L_{d,m}$		$-\Delta L_{d,m}$	
			$+\Delta L_{d,lcc}$		$-\Delta L_{d,lcc}$	
Changes in deposits	$-\Delta M_m - \Delta M_{lcc}$				$\Delta M_m + \Delta M_{lcc}$	
Firm profits	+F		$-F_m$			
			$-F_{lcc}$			
Bank profits	+FB			$-FB_m - FB_{lcc}$		
Changes in High-Powered Money				+ΔA		-ΔA
Impact certificates						+φ

funds for depreciation allowances (DA) – also decomposed into euros and LCC allowances.

Column 3 shows firms’ capital expenditures, which are financed by depreciation allowances (DA), new loans in euros ($\Delta L_{d,m}$) and in local complementary currencies ($\Delta L_{d,lcc}$). In our simple framework, profits (F) are fully redistributed to households (in euros and LCCs).

Columns 4 and 5 show the current account and the capital account of banks. As shown in column 4, banks receive interest payments on loans in euros ($r_{l,m(-1)}L_{m,-1}$) and local complementary currencies ($r_{l,lcc(-1)}L_{lcc,-1}$) and pay interests on deposits in euros ($r_{d,m(-1)}M_{h,m,s(-1)}$) and in local complementary currencies ($r_{d,lcc(-1)}M_{h,lcc,s(-1)}$). Column 5 shows that new deposits in euros (ΔM_m) and in complementary local currencies (ΔM_{lcc}) are recorded on the liability side of banks’ balance sheets. Bank assets include loans in euros ($\Delta L_{d,m}$), in local complementary currencies ($\Delta L_{d,lcc}$), and high-powered money (ΔA). The latter is emitted through the ex-post rediscounting of LCC loan impact certificates (φ). The difference between bank’s interest income from loans and interest payments and deposits, plus annual additions in reserve assets obtained through loan rediscounting, constitutes their profit, which is entirely redistributed to the household sector (in euros and LCCs) (FB). Column 6 shows the capital account of the Central Bank. In this simplified setting, the Central Bank’s only liability is the high-powered money (reserve currency) that it issues (A), in exchange for impact certificates (φ). These impact certificates measure a net contribution to SDGs, and therefore do not appear as a liability for any sector.

Behavioral equations. We begin with the definition of total gross production (GDP). GDP (Y) is the sum of all expenditures on goods and services, including consumption (C) and investment goods ($I_{f,s}$) (Eq. 1.1). GDP is decomposed into euro (Y_m) and LCC (Y_{lcc}) spending (Eqs. 1.2 and 1.3)

$$Y = C + I_{f,s} \tag{1.1}$$

$$Y_m = C_m + (I_{f,s} - I_{s,lcc}) \tag{1.2}$$

$$Y_{lcc} = Y - Y_m \tag{1.3}$$

GDP also corresponds to the sum of factor payments, which includes the wage bill (WB), production firms’ profits (F), banking profits (FB), and the depreciation and amortization funds (DA) that firms set aside to replace used-up capital. The model’s accounting closure shall ensure that Eqs. (1.4) and (1.1) are equal in all states of the model.

$$Y = WB + F + FB + DA \tag{1.4}$$

Total personal disposable income (YD) is equal to GDP net of depreciation and amortization funds (Eq. 2.1). It is also equal to the sum of euro disposable income (YD_m) and LCC disposable income (YD_{lcc}) (Eqs. 2.2 and 2.3).

$$YD = Y - DA \tag{2.1}$$

$$YD_m = Y_m - DA_m \tag{2.2}$$

$$YD_{lcc} = YD - YD_m \tag{2.3}$$

The wage bill (WB) is a fixed proportion (w) of GDP. It is decomposed into euro wages (WB_m) and LCC wages (WB_{lcc}) (Eqs. 3.1 to 3.3).

$$WB = w \cdot Y \tag{3.1}$$

$$WB_{lcc} = w \cdot Y_{lcc} \tag{3.2}$$

$$WB_m = WB - WB_{lcc} \tag{3.3}$$

Total household consumption is the sum of euro and LCC consumption. Households determine the level of euro consumption by drawing on their disposable income and on the stock of banking deposits which they inherit from the previous period. Macroeconomic consumption (in euros) depends on an autonomous incompressible component (α_0), on disposable income (YD_m) (according to a factor α_1) and euro banking deposits ($M_{h,m,s-1}$) (according to a factor $\alpha_2 < \alpha_1$). Given that households hold LCC mostly for consumption purposes, the propensity to draw from LCC income and deposits depends on a single factor α_3 (Eqs. (4.1) to (4.3)). In the baseline simulation, $shock = 0$, which means that there is no LCC consumption expenditure in

the economy (Eq. (4.3)).

$$C = C_m + C_{lcc} \tag{4.1}$$

$$C_m = \alpha_0 + \alpha_1 \left(YD_{m,-1} \right) + \alpha_2 (M_{h,m,s-1}) \tag{4.2}$$

$$C_{lcc} = shock \times \left(\alpha_{0,l} + \alpha_3 \left(YD_{lcc,-1} + M_{h,lcc,s-1} \right) \right) \tag{4.3}$$

We now describe the budget constraint and the portfolio behavior of households. We follow Godley and Lavoie (2012, ch.4) and model households' demand for liquid assets (which includes sight deposits and LCCs) as a buffer, which varies according to unexpected variations in household income. At the end of each year, whatever total disposable income (YD) not spent on consumption (C) is added to households' total financial wealth M_h (5.1). Households' euro-denominated holdings are determined using similar principles (Eq. 5.2). Households' LCC holdings is determined using an accounting criterion (Eq. (5.3)).

$$\Delta M_h = M_h - M_{h-1} = YD - C \tag{5.1}$$

$$\Delta M_{h,m} = YD_m - C_{d,m} \tag{5.2}$$

$$\Delta M_{h,lcc} = \Delta M_h - \Delta M_{h,m} \tag{5.3}$$

The model contains three financial assets: savings account deposits, sight deposits (both in euros) and LCC holdings. Households' demand for savings account deposits ($\Delta M_{h,m,d}$) depends on their expected total financial wealth (M^e) and expected euro disposable income (YD^e).

Households wish to hold a given proportion (λ_0) of their expected wealth in the form of savings account deposits, and this proportion increases with their expected disposable income, according to a parameter $\lambda_1 > 0$ (Eq. (6.1)). Households' targeted holdings of sight deposits ($\Delta M_{h,h,d}$) can then be determined with an accounting closure criterion, as shown in Eq. (6.2). Finally, whatever amount of LCCs is not spent at the end of the year is simply added to the stock of LCC holdings (6.3). In the baseline scenario, $shock = 0$ so that households do not allocate any share of their wealth in LCCs. The supply of financial assets is equal to demand (Eqs. (6.4) to (6.6)).

$$\frac{\Delta M_{h,m,d}}{M^e} = \lambda_0 + \lambda_1 \frac{YD_{m,-1}^e}{M_h} \tag{6.1}$$

$$\Delta M_{h,h,d} = \Delta M_{h,m} - \Delta M_{h,m,d} \tag{6.2}$$

$$M_{h,lcc,d} = shock \times \left(M_{lcc,-1} + YD_{lcc} - C_{lcc} \right) \tag{6.3}$$

$$\Delta M_{h,m,s} = \Delta M_{h,m,d} \tag{6.4}$$

$$\Delta M_{h,h,s} = \Delta M_{h,h,d} \tag{6.5}$$

$$\Delta M_{h,lcc,s} = \Delta M_{h,lcc,d} \tag{6.6}$$

Expected wealth (M^e) is the mirror of realized wealth (equation (5)) in the realm of expectations. It is defined in Eq. (7):

$$M^e = M_{h,-1} + (YD^e - C) \tag{7}$$

Expected euro disposable income (YD_m^e) is modeled as a weighted average of its past and expected value (Godley and Lavoie 2012, p.291) (Eq. (8)).

$$YD_m^e = \epsilon YD_{m,-1} + (1 - \epsilon) YD_{m,-1}^e \tag{8}$$

Let us now look at the production sector. In both the euro and LCC-denominated sectors, the demand for investment ($I_{f,m,d}$ and $I_{f,lcc,d}$, respectively) is based on the partial accelerator model and

has two components: the first is forward-looking and adjusts partially ($\gamma < 1$) to the discrepancy between the targeted capital stock (K^T) and the stock of productive assets (K_{-1}) inherited from the previous period. The second component consists in expenditure required to replace the used-up machines (DA) (equation (11)):

$$I_{f,m,d} = \gamma \left(K_m^T - K_{m,-1} \right) + DA_m \tag{11.1}$$

$$I_{f,lcc,d} = \gamma \left(K_{lcc}^T - K_{lcc,-1} \right) + DA_{lcc} \tag{11.2}$$

In both sectors, depreciation and amortization funds (DA) are defined as a fixed proportion ($0 < \delta < 1$) of the stock of capital (K_{-1}) that firms hold at the beginning of the fiscal year (equation (12)).

$$DA_m = \delta K_{m-1} \tag{12.1}$$

$$DA_{lcc} = \delta K_{lcc-1} \tag{12.2}$$

Entrepreneurs have adaptive expectations and index the targeted capital stock (K^T) to total macroeconomic income achieved in the previous period (Eq. (13.1)). However, LCC sector entrepreneurs adjust their capital stock target in reference to LCC-denominated income (i.e. to the size of the LCC community) (Eq. (13.2)).

$$K_m^T = \kappa Y_{-1} \tag{13.1}$$

$$K_{lcc}^T = \kappa Y_{lcc-1} \tag{13.2}$$

The stock of productive capital (K) is equal to the stock inherited from the previous period (K_{-1}) net of depreciation allowances (δK_{-1}), plus newly acquired capital ($I_{f,s}$) (equation (14)). It is decomposed into euro and LCC denominated capital (equation (14)).

$$K_m = (1 - \delta) K_{m,-1} + I_{f,m,s} \tag{14.1}$$

$$K_{lcc} = (1 - \delta) K_{lcc,-1} + I_{f,lcc,s} \tag{14.2}$$

$$K = K_m + K_{lcc} \tag{14.3}$$

The above framework ensures that the introduction of LCCs affects both firms' investment behavior and the stock of productive capital. Sectoral balance sheets track the euro and LCC components of physical capital assets, amortization funds, capital stock targets, financial wealth and income flows.

The profits of both banks and productive firms are fully distributed as dividends to the household sector. Thus, firms finance net investment through new bank loans. Money creation results from the interplay between firms' productive bets and banks' lending decisions. The demand for new loans (ΔL_d) equals the net demand for investment, i.e. the difference between gross demand for investment ($I_{f,d}$) and set-aside amortization funds (DA) in euros and LCCs (Eqs. (16.1) to (16.3)). In the baseline simulations, $shock$ is set to zero and there is no demand for credit in LCCs (Eq. (16.2)).

$$\Delta L_{f,d,m} = I_{f,d,m} - DA_m \tag{16.1}$$

$$\Delta L_{f,d,lcc} = shock \times (I_{f,d,lcc} - DA_{lcc}) \tag{16.2}$$

$$\Delta L_{f,d} = \Delta L_{f,d,m} + \Delta L_{f,d,lcc} \tag{16.3}$$

The afflux of money is described in Eqs. (17.1) to (17.6). Banks screen euro loans applications based on the expected credit-worthiness of borrowers (ρ) (Eq. (17.1)). The supply of LCC loans

equals demand from LCC firms, plus a fraction (which we set to one) of the rejected applications for euro-loans.

We assume that banks reject SDG-contributing, yet non-creditworthy demand for investment. Yet, these investments carry a positive SDG impact, which banks can rediscount at the Central Bank. In the baseline simulations *shock* is set to zero so that euro-investment is constrained and no LCC credit takes place (Eq. (17.2)). Equations (17.3) to (17.6) are accounting equations defining the stock of loans and annual total, euro and LCC investment, respectively.

$$\Delta L_{f,s,m} = L_{f,d,m}(1 - \rho) \tag{17.1}$$

$$\Delta L_{f,s,lcc} = shock \times (L_{f,d,cc} + (\rho L_{f,d,m})) \tag{17.2}$$

$$L_s = L_{f,s,m} + L_{f,s,lcc} \tag{17.3}$$

$$I_{f,s,m} = \Delta L_{f,s,m} + DA_m \tag{17.4}$$

$$I_{f,s,lcc} = \Delta L_{f,s,lcc} + DA_{lcc} \tag{17.5}$$

$$I_{f,s} = I_{f,s,m} + I_{f,s,lcc} \tag{17.6}$$

At each period, productive firms' profits are equal to the difference between GDP and other factor payments (using the income definition for GDP) (Eq. (18.1)). Profits are broken down into euro and LCC profits (Eqs. (18.2) and (18.3)) here

$$F = Y - WB - FB - DA - r_{d,m,-1}M_{h,m,s,-1} - r_{d,lcc,-1}M_{h,lcc,s,-1} \tag{18.1}$$

$$F_{lcc} = Y_{lcc} - WB_{lcc} - FB_{lcc} - DA_{lcc} - r_{d,lcc,-1}M_{h,lcc,s,-1} \tag{18.2}$$

$$F_m = Y_m - WB_m - FB_m - DA_m - r_{d,m,-1}M_{h,m,s,-1} \tag{18.3}$$

Banks charge different interest on loans issued in euros ($r_{l,m}(L_{s,m,-1})$) and LCC ($r_{l,lcc}(L_{s,lcc,-1})$). Their profit is the interest spread, plus any new reserve assets ΔA_s obtained from the Central Bank through impact rediscounting. Rediscounting implies that LCC loans are less risky from the banks' perspective. We thus set $r_{l,lcc} < r_{l,m}$ (see Table A2 in the appendix) (Eq. (19)).

$$FB = r_{l,m}(L_{s,m,-1}) + r_{l,lcc}(L_{s,lcc,-1}) + \Delta A_s - r_{d,m}(M_{s,m,-1}) - r_{d,lcc}(M_{lcc,-1}) \tag{19}$$

We now turn to the Central Bank's rediscounting policy. As discussed, impact rating agencies compute the annual SROI of the circulation of the LCC deposits emitted through bank loans at the previous period. Banks obtain an annual flow of impact certificates (φ_s) (Eqs. (20.1) and (20.2)).

$$\varphi_d = (1 + SROI)L_{s,lcc,-1} \tag{20.1}$$

$$\varphi_s = \varphi_d \tag{20.2}$$

Banks swap these impact certificates for new reserve assets at the Central Bank.

The Central Bank applies a haircut (τ) in this transaction (Eq. (21.2)). The haircut rate is a discretionary yet, as shown in Eq. (22), we model it as an endogenous variable. The haircut rate depends on two components: its past value, and the product of normally distributed random shocks (ε) (reflecting the evolution of the monetary policy framework) and first-differenced impact ratings. This means that an increase in the SDG performance of LCC loans shall lead Central Banks to decrease of the haircut rate, subject to any other random shock (ε). We set the starting value of the haircut rate at 4.5%, which corresponds to the valuation

markdown which the ECB applied to asset-backed securities at the time of writing (European Central Bank 2022a, b).

$$H_s = A_d \tag{21.1}$$

$$A_d = (1 - \tau) \cdot \varphi_{s,-1} \tag{21.2}$$

$$\tau = \tau_{-1} + \varepsilon \Delta SROI \tag{22}$$

Interest rates are set as exogenous parameters. SROI impact ratings of LCC deposits are modeled as a stochastic process, with annual random innovations ξ following a Laplace distribution around a mean of 15% (Walter 2020) (Eqs. (23.1) to (23.5)).

$$r_{l,m} = \overline{r_{l,m}} \tag{23.1}$$

$$r_{l,lcc} = \overline{r_{l,lcc}} \tag{23.2}$$

$$r_{c,m} = \overline{r_{d,m}} \tag{23.3}$$

$$r_{d,lcc} = \overline{r_{d,lcc}} \tag{23.4}$$

$$SROI = \overline{SROI} + \xi \tag{23.5}$$

The supply of money (M_h) (in euros and local complementary currency) held by households is modeled in Eq. (5.1). New loans (in euros and local complementary currency) recorded in banks' balance sheets are given by Eq. (17.3). Although the supply and demand of bank deposits depend on different process, they shall be equal in all states of the model by virtue of its accounting consistency (i.e. without any equilibrium condition being imposed). Equation (24) is therefore the model's hidden equation. This feature of the model qualifies it as a post-Keynesian SFC model insofar as money creation is entirely driven by the behavior of banks and productive firms. The model assumes no multiplier mechanism that would run from the reserves to new deposit creation by private banks (Bank of England 2014; Wray 2012; Ehnts 2017).

$$\Delta M_h = \Delta L_s \tag{24}$$

Finally, the model features a resilience block based on Ulanowicz et al. (2009). This requires us to introduce the following definitions. Let T_i represent the expenditure of each sector i to any other sector; T_j is the net income of sector j from any other sector; and T_{ij} the expenditure of any sector i to any sector j . The sum of all net transfers of money between sectors i and j is $T_{..} = \sum_{ij} T_{ij}$. We focus on private sector transactions only, and consider households (h), banks (b) and productive firms (f).

Equation (24.1) shows that the expenditure of household to other units (T_h) equates consumption spending to the firm sector, in the legal tender and in LCCs ($C_m + C_{lcc}$). Equation (24.2) shows that the income of households from other sectors (T_h) is the sum of wages and distributed profits paid by productive firms in the legal tender and in LCCs ($WB_m + WB_{lcc} + F_m + F_{lcc}$), interest payments and distributed profits from banks ($r_{l,m}(L_{s,m,-1}) + r_{l,lcc}(L_{s,lcc,-1}) + FB$).

Equation (24.3) shows that the expenditure of productive firms to other units (T_f) is the sum of net investment spending ($\Delta L_{s,m} + \Delta L_{s,lcc}$), wages and profits paid to the household sector ($WB_m + WB_{lcc} + F_m + F_{lcc}$), and interest paid to the banking sector ($r_{l,m}(L_{s,m,-1}) + r_{l,lcc}(L_{s,lcc,-1})$).

Equation (24.4) shows that the net income of productive firms from other units (T_f) is the sum of the new loans issued by the banking sector ($\Delta L_{s,m} + \Delta L_{s,lcc}$) and household consumption ($C_m + C_{lcc}$).



Fig. 4 Accounting closure. Source: author’s simulations. The replication code is available upon request.

Equation (24.5) defines the banking sector’s expenditure (T_b) to other units as the sum of new loans issued to productive firms ($L_{s,m} + L_{s,lcc}$), interest payments, and profits distributed to households ($r_{d,M}(M_{s,m,-1}) + r_{d,lcc}(M_{lcc,-1}) + FB$). Equation (24.6) measures the income of the banking sector (T_b) as the sum of the interest payments received from productive firms ($r_{l,M}(L_{s,m,-1}) + r_{l,lcc}(L_{s,lcc,-1})$).

$$T_h = C_m + C_{lcc} \tag{25.1}$$

$$T_h = WB_m + WB_{lcc} + F_m + F_{lcc} + r_{d,M}(M_{s,m,-1}) + r_{d,lcc}(M_{lcc,-1}) + FB \tag{25.2}$$

$$T_f = L_{s,m} + L_{s,lcc} + WB_m + WB_{lcc} + r_{l,M}(L_{s,m,-1}) + r_{l,lcc}(L_{s,lcc,-1}) + F_m + F_{lcc} \tag{25.3}$$

$$T_f = L_{s,m} + L_{s,lcc} + C_m + C_{lcc} \tag{25.4}$$

$$T_b = L_{s,m} + L_{s,lcc} + r_{d,M}(M_{s,m,-1}) + r_{d,lcc}(M_{lcc,-1}) + FB \tag{25.5}$$

$$T_b = r_{l,M}(L_{s,m,-1}) + r_{l,lcc}(L_{s,lcc,-1}) \tag{25.6}$$

Defining the sum of all net transfers of money between units i and j as $T_{..} = \sum_{ij} T_{ij}$, the occurrence probability of each transaction is equal to its observation frequency:

$$p_{ij} = \frac{T_{ij}}{T_{..}}; p_{i.} = \frac{T_{i.}}{T_{..}}; p_{.j} = \frac{T_{.j}}{T_{..}}$$

Following Ulanowicz et al. (2009), we can now define the evolutionary capacity of the economic system as $C = A + \Phi$. Each term is defined in Eqs. (26.1) to (26.3):

$$C = - \sum_{ij} T_{ij} \log \left(\frac{T_{ij}}{T_{..}} \right) \tag{26.1}$$

$$A = \sum_{ij} T_{ij} \log \left(\frac{T_{ij} T_{..}}{T_{i.} T_{.j}} \right) \tag{26.2}$$

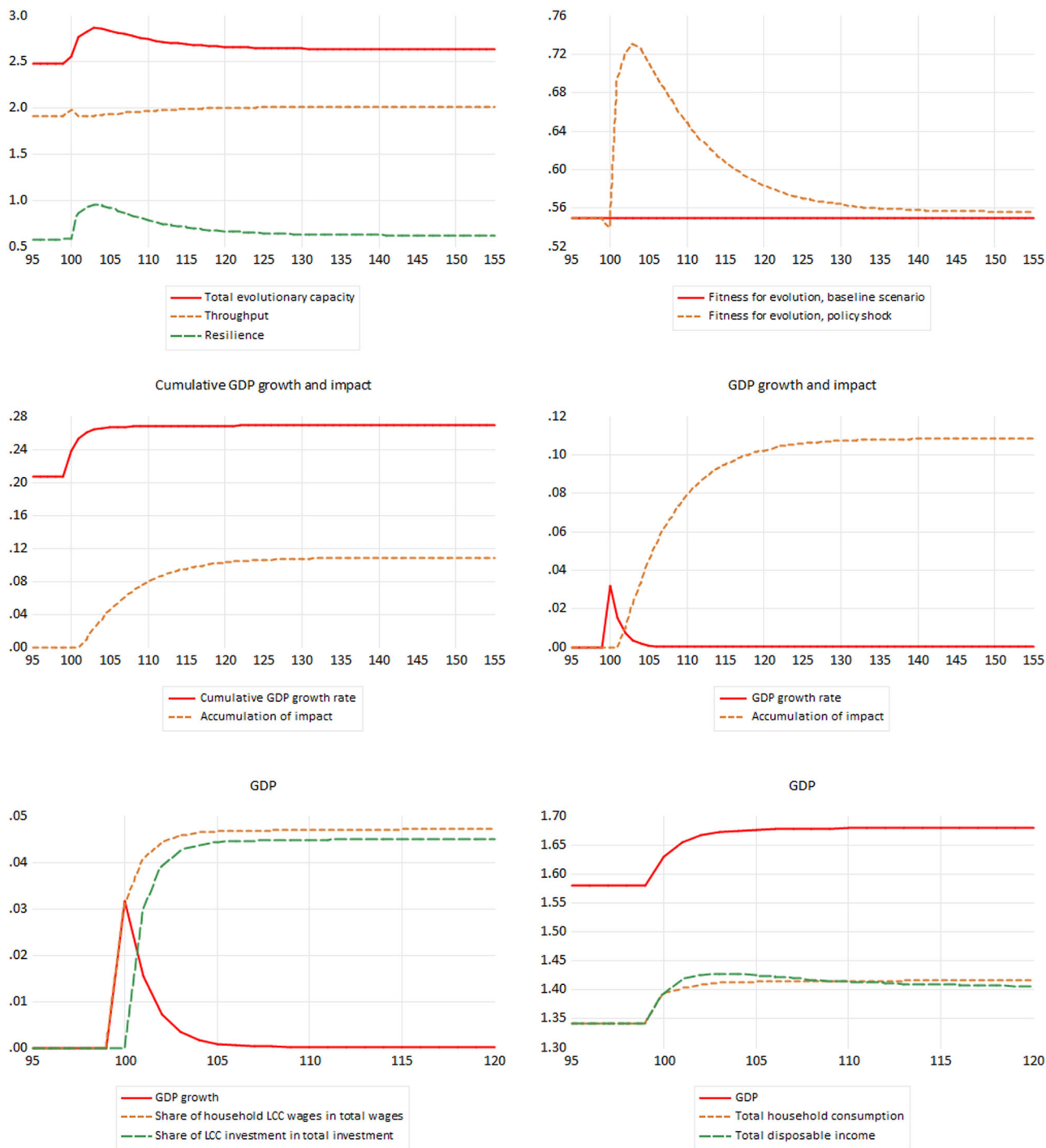


Fig. 5 Biomimicry scores and macroeconomic dynamics. Source: author’s simulations. The replication code is available upon request.

$$\Phi = - \sum_{ij} T_{ij} \log \left(\frac{T_{ij}^2}{T_i T_j} \right) \tag{26.3}$$

Letting $a = \frac{\Delta}{C}$ and applying a Boltzmann transformation yields the system’s fitness for evolution metric F (Eq. (27)):

$$F = -ka \log(a) \tag{27}$$

Where k is a positive scalar set to 2.71. As discussed in Section 2.2., when $a = 1$, F tends to zero due to a lack of resilience. When

$a = 0$, F also tends to zero due to a lack of ascendency. F increases for intermediate values of a and peaks when $a = \frac{1}{e} = 0.36$ (see Fig. 1).

Simulation results

Numerical properties. Our model respects the four validity criteria put forth in Godley and Lavoie (2012) and used in the stock-flow consistent modeling literature:

- (i) One implicit accounting equality holds in all periods and all states of the model. As discussed in Eq. (24) and shown in

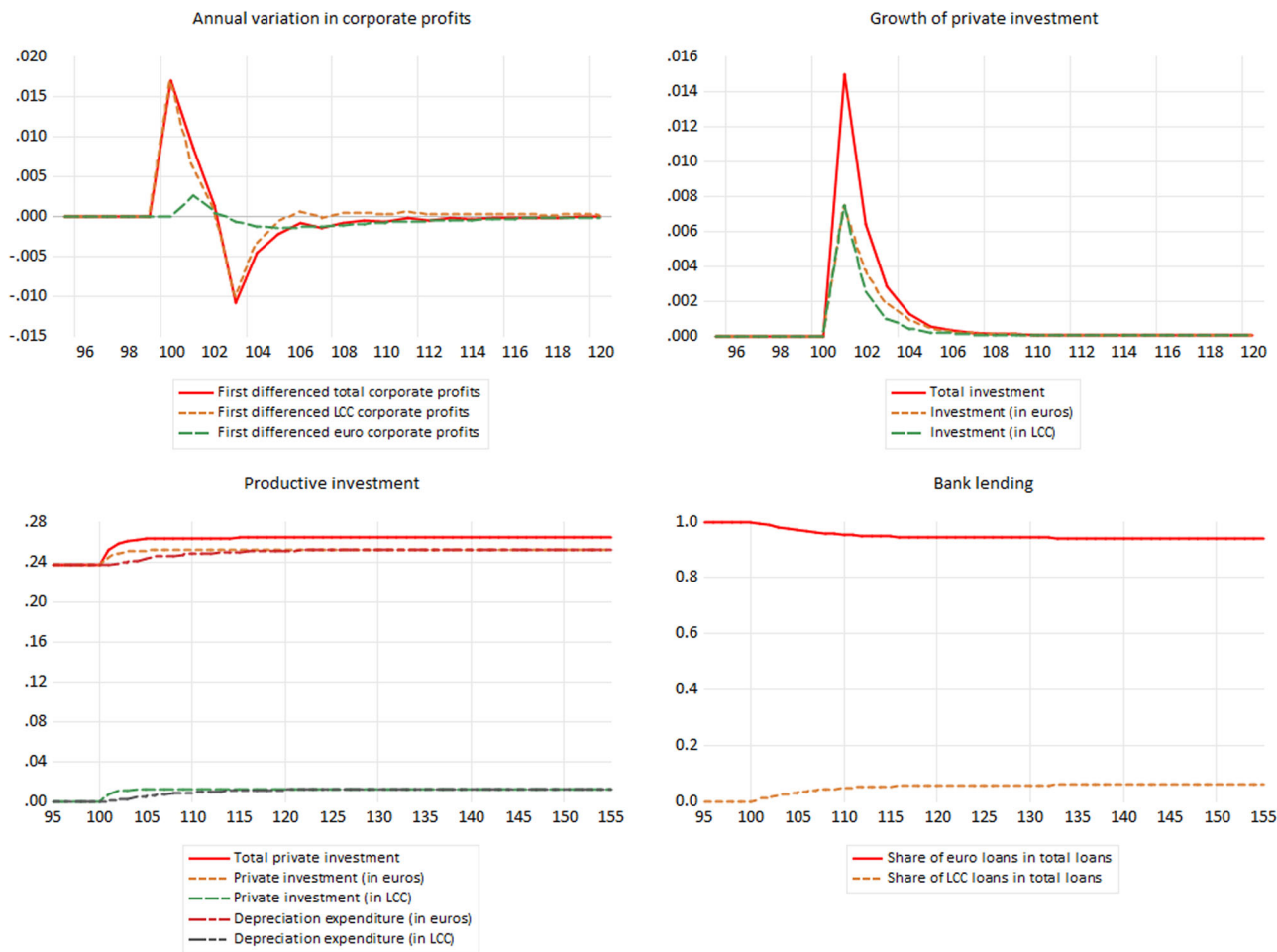


Fig. 6 Investment and profits. Source: author’s simulations. The replication code is available upon request.

Fig. 3, additions to household deposits are equal to new bank loans to productive firms. Yet, the model contains no equilibrium condition which makes the two equal to one another;

- (ii) Using the Broyden algorithm, the model reaches a stationary state (with a GDP of 1,579,375) after 10 replications. This stationary state holds for 1000 periods;
- (iii) The model allows for a coherent stock-flow integration of income and financial accounting in line with the National Income and Product Account (NIPA). As shown in Fig. 3, the expenditure and income definitions of GDP (Eqs. (1.1) and (1.4)) are equal in all states of the model—even though the former relies on flows, and the latter on both stocks and flows.
- (iv) Stocks of assets, liabilities, and flows of income and spending take meaningful values in all states of the model. This allows to interpret causal relationships between income, stocks, and rates of return over several assets, and model to financial operations.

The bottom right quadrant of Fig. 4 shows the values of annual SROI impact metrics. These are modeled through a Laplace distribution centered around a mean of 15%. This figure also reports the value of the Central Bank’s haircut rate τ (Eq. 22).

Simulation strategy. We set $shock = 0$ in Eqs. (4.3), (6.3), (16.2) and (17.2), and bring the model to stationary steady-state¹². In this baseline scenario, banks do not issue LCC loans and do not

operate a conversion desk for households. Therefore, there is no impact rediscounting by the Central Bank either.

We then set $shock = 1$. This allows LCC circulation, LCC lending and the impact rediscounting mechanism to kick in. Holding all other parameters constant, we inspect the response of the entire system, as it transits towards a new stationary steady-state.

Results. Figures 5–7 display the response of the models’ key variables¹³. Due to a higher resilience, capacity for evolution and fitness for evolution metrics both increase significantly. We also observe a short-run, SDG-driven economic expansion. Both GDP and SROI impact certificates (*‘Philia’*) increase in the short-run and stabilize in the long-run. GDP growth peaks at 3% and vanishes after seven periods. The share of LCC investment in total private investment and the share of LCC wages in total wages are both permanently higher. Therefore, these figures indicate that economy has undergone sustainable structural change.

As shown in Fig. 5, the policy shock induces a short-turn increase in macroeconomic spending, which increases private sector profits. The circulation of LCCs also triggers an expansion of the social business sector, contributing to sustainable structural change.

Macroeconomic private investment increases due to additional LCC loans to the social business sector. Entrepreneurs in other sectors of the economy respond to increased economic growth by adjusting their capital target upwards, which increases euro investment as well (equation (13)).

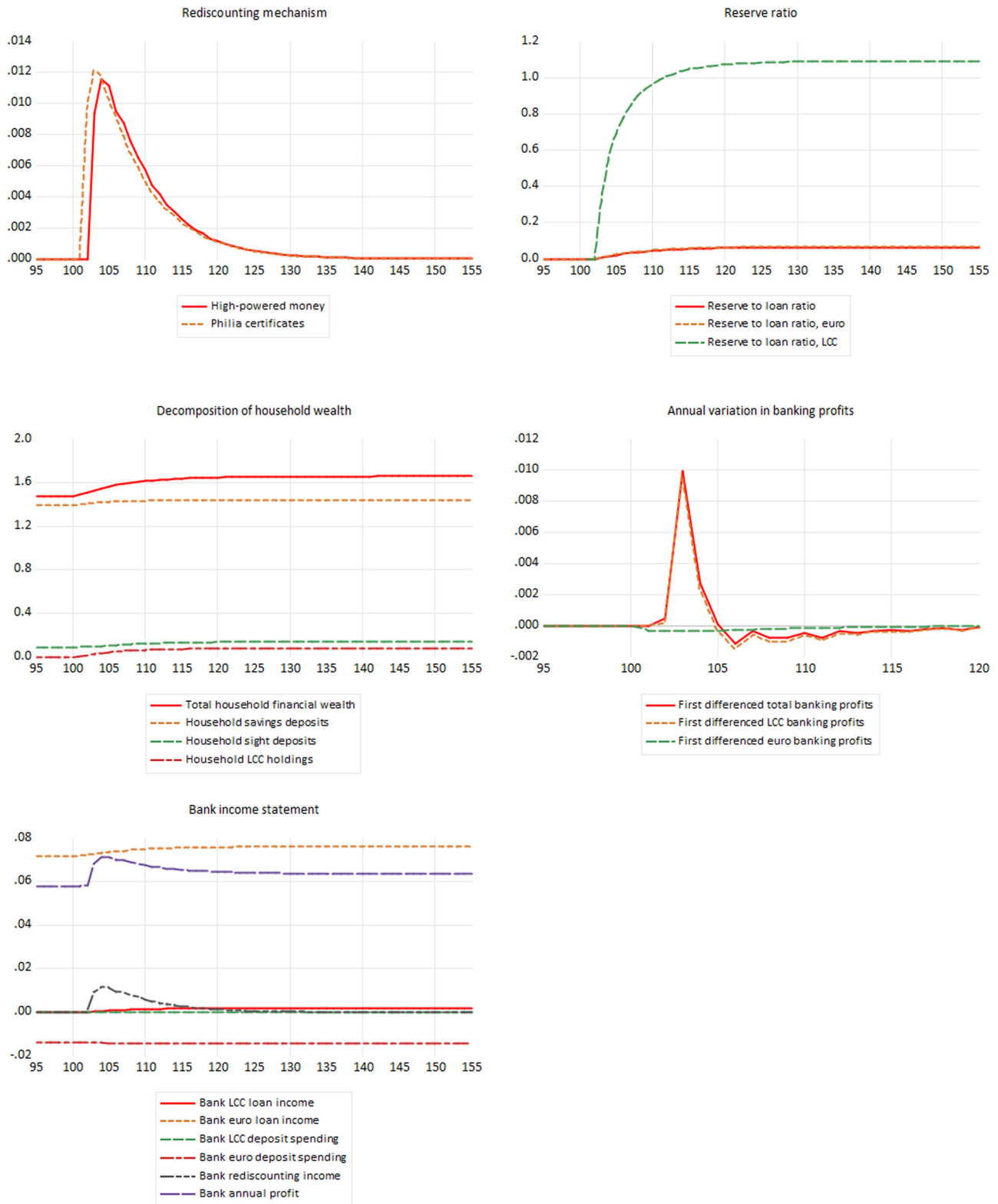


Fig. 7 Money and finance. Source: author’s simulations. The replication code is available upon request.

The impact of this dynamic on sustainability is ambiguous. LCC-induced economic growth might indeed spill-over to the ‘brown’ sector. On the other hand, additional investment in euros is likely to affect sectors or territories in which an LCC-driven expansion has taken place, thereby accelerating the SDG transformation. More empirical analysis as well as field work is

needed to determine the conditions leading one of these two mechanisms to dominate the other.

Figure 7 displays the monetary and financial side of the model. The Central Bank credits the banking sector with new reserves in exchange for new impact certificates. This policy appears to enhance financial stability as the banking sector posts a higher

reserve to loan ratio. Banking sector profits increase due to the higher volume, and to annual net flows of reserve assets. Total household financial wealth increases and appears to diversify, with households holding LCC assets along with sight and savings deposits in euros. This new asset structure locks up a portion of household wealth for sustainable consumption purposes, contributing to sustainable structural change.

Conclusion

Scaling up SDG financing requires innovative approaches and bold policy decisions (UN 2023). This paper thus contributed to the SDG finance literature by putting forth a prototype policy seeking to endogenize the creation of LCC deposits in the economy. We laid out a framework in which banks would issue LCC loans linking up LCC deposit creation to future productive bets. LCC convertibility in the legal tender is implied by Central Bank rediscounting of the ex-post SDG impact of LCC loans.

We then attempted to raise analytical insight on this new idea by developing a new PK-SFC model comprised 106 accounting and behavioral equations and biomimetic indicators. Our simulations suggested that this prototype policy may generate a short-lived economic expansion embedded in the SDGs, while also increasing banking stability. We also observed an increase the economy's total capacity for development, resilience, and fitness for evolution, in line with Lietaer et al. (2012).

This policy prototype is promising but calls for additional research. A more elaborate SFC model should consider endogenous structural change, which is an important component when discussing the transition to an ecologically sensitive economic structure (Caiani et al. 2014). The policy mechanism should be refined by drawing lessons from the history of policy innovations, with a focus on governance, accountability, and incentives. Finally, we need to develop new databases to be able to measure the SDG impact of LCCs, as well as the value of multipliers.

We call for multilateral institutions to support this new approach to SDG financing by undertaking small-scale, pilot experiments. As the success of such experiments would require strong actor engagement, developing a strong trust relationship between multilateral institutions, domestic banks, Central Banks and LCC communities appears of utmost importance. We thus call for the organization of regular multilateral workshops around this project to create a feedback loop between economists, policy makers, multilateral institutions, and local stakeholders. Such workshops would provide a community of practice for small-scale policy experiments, allowing countries with varying development paths to share and draw lessons from each other's experiences. If successful, such small-scale experiments could eventually be upscaled and contribute to a new sustainable economic model in line with the SDGs.

Data availability

The Eviews code is available from the contact author upon request.

Received: 3 March 2023; Accepted: 26 March 2024;

Published online: 30 April 2024

Notes

- 1 The supply of major LCCs such as the Bristol Pound in the UK, the Eusko in the Southwestern France, or the Chiemgauer in Bavaria is indeed backed up by deposits in the legal tender.

- 2 “Nature does not select for maximum efficiency, but for a balance between the two opposing poles of efficiency and resilience. Because both are indispensable for long-term sustainability and health, the healthiest flow systems are those that are closest to an optimal balance between these two opposing pulls. Conversely, an excess of either attribute leads to systemic instability. Too much efficiency leads to brittleness and too much resilience leads to stagnation: the former is caused by too little diversity and connectivity and the latter by too much diversity and connectivity” (Lietaer et al., 2010, p.6).
- 3 Appendix 2 discusses the fitness for evolution function.
- 4 In a clearinghouse, the assets of some are the liabilities of others. Such a tool allows to untie the bilateral side of the debt and to create a multilateral compensation between the different participants increasing liquidity.
- 5 Unspent *com.mons* after three years are exchanged either into currency (assets sold on the market) or into unsold assets.
- 6 For instance, the European Central Bank (ECB) abide to the 1992 Maastricht Treaty outlining the promotion of sustainable development as a cornerstone of the European Union. Many Central Banks around the world—especially in emerging and developing countries—are increasingly taking ecological and social objectives into account (Dikau and Volz 2021). At the European level, a recent step was also taken in this direction, with the ECB committing to decarbonizing its corporate bond purchasing and collateral framework (European Central Bank 2022).
- 7 In Europe, several branches of local government accept LCCs in payment of taxes, and make outgoing payments in LCCs (such as Bristol Pound in the UK, or the Eusko in Bayonne (France)).
- 8 In recent years, participative methods such as the social return on investment (SROI) method have gained traction to measure monetized ecological and social impact at the project-scale level ((Raïden and King 2021; World Health Organization 2017). These methods permit to construct worthiness and value creation for activities, even in cases where no actual cash flows are generated (Yates and Marra 2017; Cooney 2017).
- 9 The evaluation of shadow prices is not an easy task, and their use does not guarantee the success of the policy per se. As pointed out by an anonymous referee, shadow prices should ideally incorporate all the interrelationships between objectives and constraints that characterize a given economy. Given that our knowledge about them is too limited, shadow prices can often appear artificial. Policy makers wishing to test the proposed mechanism should thus carefully analyze experience with shadow prices at an international level.
- 10 Private credit ratings agencies suffer from “birth defects, notably conflict of interests, biased decision-making, oligopoly, wrong business model and lack of transparency” (Li 2020, p. 1). According to the UNCTAD (2020, p. 131) “ratings agencies, like banks, act in a pro-cyclical manner that (...) accentuates broader financial sector vulnerabilities (...). It is not appropriate that credit rating agencies should continue to hold this de facto role of arbiters of responsible financial behavior – especially when they are also players in the same market they regulate”.
- 11 Theoretical foundations and methodological guidelines for PK-SFC modeling can be found in Godley and Lavoie’s (2012) seminal book.
- 12 In a stationary steady-state, stock and flow variables are in a constant relationship to each other and stable in levels. Such a state is unlikely to be reached in the real world where parameters and structural relationship move all the time. It is a numerical construct which permits to monitor the stream of causal sequences impulse by a specific shock to the economic system, as it transits towards a new steady state.
- 13 The Eviews code is available upon request from the contact author.

References

- Aglietta M (2018) Money: 5000 years of debt and power. Verso, 432
- Aglietta M, Espagne E (2016) Climate and finance systemic risks, more than an analogy? The climate fragility hypothesis. CEPII Working Paper, N°2016-10, April 2016
- Amato M, Fantacci L (2016) Failures on the market and market failures: a complementary currency for bankruptcy procedures. *Camb J Econ* 40(5):1377–1395
- Ansart S, Monvoisin V (2017) The new monetary and financial initiatives: Finance regaining its position as servant of the economy. *Res Int Bus Financ* 39:750–760. Elsevier
- Bank of England (2014) Money creation in the modern economy. *Q Bull* 1:14–27
- Blanc J (2011) Classifying ‘CCs: community, complementary and local currencies’ types and generations. *Int J Community Curr Res* 15:4–10
- Blanc J (2017) Unpacking monetary complementarity and competition: a conceptual framework. *Camb J Econ* 41(1):239–257
- Blanc J (2018) Tensions in the triangle: monetary plurality between institutional integration, competition and complementarity. *Evolut Inst Econ Rev Jpn Assoc Evolut Econ* 1(2):389–411. <https://doi.org/10.1007/s40844-018-0101-1>
- Blanc J (2022) Money and the ecological turn: lessons from alternative currencies. Working Paper
- Blanc J, Fare M (2016) Turning values concrete: the role and ways of business selection in local currency schemes. *Rev Soc Econ* 74(3):298–319

- Blanc J, Lakócai C (2020) Toward spatial analyses of local currencies: the case of France. *Int J Community Curr Res Res Assoc Monetary Innov Complementary Community Currencies (RAMICS)* 24(1):11–29. <https://doi.org/10.15133/j.jicr.2020.002>
- Blanc J, Perrissin Fabert B (2016) Financer la transition écologique des territoires par les monnaies locales, Institut Veblen pour les réformes économiques, p 24
- Bourghelle D (2023) Understanding financial markets. In Lagoarde-Segot T (ed) *Ecological Money and Finance. Exploring Sustainable Monetary and Finance Systems*, Chap 11, Palgrave-Macmillan, UK, pp 692
- Buck JA, Enderburg G (2004) La sociocratie : les forces créatives de l'auto-organisation, traduction Charest G., site de l'Association Lyonnaise d'Éthique Économique et Sociale, http://www.lyon-thique.org/IMG/pdf/buck_enderburg_la_soc_iocratie_les_forces_c_reatives_de_l_auto_organisation-1.pdf
- Caiani A, Godin A, Lucarelli S (2014) A stock flow consistent analysis of a schumpeterian innovation economy. *Metroeconomica* 65(3):397–42. Wiley Blackwell
- Carrillo P (2018) Identification of barriers and solutions for adoption of social, complementary and/or virtual currencies. *Int J Community Curr Res* 22:125–140
- Cauvet M, Perrissin Fabert B (2018) Les monnaies locales: vers un développement responsable. La transition écologique et solidaire des territoires, Paris, Rue d'Ulm, coll. « Sciences durables », 128 p., preface from Michel Aglietta, ISBN: 978-2-7288-0583-9
- Chambost I, Lenglet M, Tadjeddine Y (2019) *The Making of Finance: Perspectives from the Social Sciences*. Routledge, Oxon, UK
- Cobham, D (2023) Monetary policy frameworks since Bretton Woods, across the world and its regions. *Rev World Econ* <https://doi.org/10.1007/s10290-023-00517-1>
- Cooney K (2017) Legitimation dynamics: how SROI could mobilize resources for new constituencies? *Evaluat Program Plan* 64:110–115
- Coutrot T, Thérét B (2019a) Tax-credit instruments as complementary currencies: a policy proposal for fighting the austerity while saving the euro zone. 5th Biennial RAMICS International Congress, Sep 2019, Hida-Takayama, Japan
- Coutrot T, Thérét B (2019b) Système fiscal de paiement complémentaire: un dispositif pour renverser l'hégémonie. *Rev Française de Socio-Econ* 1(22):163–170
- Drèze J, Nicholas S (1988) Policy Reform, Shadow Prices, and Market Prices. IMF Working Paper No. 88/91, Available at SSRN: <https://ssrn.com/abstract=885049>
- Didier R (2022) Monnaie : communauté ou institution? Un éclairage théorique et empirique à partir d'une monnaie locale. Thèse de doctorat, sous la direction de Yamina Tadjeddine-Fourneyron, Université de Lorraine
- Dikau S, Volz U (2021) Central bank mandates, sustainability objectives and the promotion of green finance. *Ecol. Econ.* 184:107022. <https://doi.org/10.1016/j.ecolecon.2021.107022>
- Ehnts DH (2017) *Modern Monetary Theory and European Macroeconomic*. Routledge, Oxon, UK
- Escobar AL, López RR, Solano-Sánchez MA, de los Baños García-Moreno M (2020) The role of complementary monetary system as an instrument to innovate the local financial system. *J Open Innov: Technol Mark Complex* 6(4):141. <https://doi.org/10.3390/joitmc6040141>
- European Central Bank (2022a) ECB takes further steps to incorporate climate change into its monetary policy operations. Press Release July 4th, 2022. <https://www.ecb.europa.eu/press/pr/date/2022/html/ecb.pr220704-4f48a72462.en.html#:~:text=The%20ECB%20is%20also%20including,statistical%20data%20and%20corporate%20sustainability>
- Fare M, Ould Ahmed P (2017) Complementary Currency Systems and their Ability to Support Economic and Social Changes. *Develop Change* 48(5):847–872
- Fantacci L (2005) Complementary currencies: a prospect on money from a retrospect on premodern practices. *Financ History Rev* 12(1):43–61
- Fantacci L (2008) The dual currency system of Renaissance Europe. *Financ History Rev* 15(1):55–72
- Federal Reserve (1942) Twenty-Ninth Annual Report of the Board of Governors of the Federal Reserve System Covering Operations of the Year. Federal Reserve, Washington, DC, USA
- Fois Duclerc M, Lafuente-Sampietro O (2023) Un intermédiaire monétaire créateur de proximités territoriales : la structuration d'un réseau d'entreprises autour de la monnaie locale eusko au Pays Basque ». *Rev. d'Écon R.égion Urbain* 2023(no. 1):83–109. vol
- García-Corral FJ et al. (2020) Complementary currencies: an analysis of the creation process based on sustainable local development principles. *Sustainability* 12(4):5672–5694
- Gesell S (1929) *The Natural Economic Order*. Neo-Verlag, Berlin-Frohnau
- Godley W, Lavoie M (2012) *Monetary Economics. An Integrated Approach to Credit, Money, Income, Production and Wealth*. Palgrave-MacMillan, UK
- Graziani A (2003) *The Monetary Production Economy*. Cambridge University Press, UK, pp 176
- Granovetter M (1973) The strength of weak ties. *America J Socio* 78(6):1360–1380
- Lafuente-Sampietro O (2023) Des monnaies locales pour le développement territorial ? Une application de la théorie de la base économique aux monnaies locales convertibles. *Rev d'Écon R.égion Urbain* 2023(no. 2):281–301
- Lagoarde-Segot T, Paraque B (2018) Finance and sustainability: from ideology to utopia. *Int Rev Financial Anal* 55:80–92
- Leclercq Y (1982) Les transferts financiers. Etat-compagnies privées de chemin de fer d'intérêt général (1833–1908). *Rev. Econ* 33:896–924
- Le Velly, R (2002) La notion d'encastrement: une sociologie des échanges marchands. *Sociologie du Travail, Association pour le développement de la sociologie du travail* 44(1):37–53
- Li Y (2020) Informal Summary (rev) of report of Independent Expert on foreign debt and human rights, A/HRC/46/29- Advanced Edited Version. United Nations Human Rights Special Procedure
- Lietaer B, Ulanowicz RE, Goerner S, MacLaren N (2010) Is our monetary structure a systemic cause for financial instability? Evidence and remedies from nature. *J Futures Stud Special Issue Financ Crisis*
- Lietaer B, Arnsperger C, Goerner S, Brunnhuber S (2012) *A report from the club of rome – EU Chapter to Finance Watch and the World Business Academy*. Triarchy Press 2012
- Lucarelli S, Gobbi L (2016) Local clearing unions as stabilisers of local economic systems: a stock flow consistent perspective. *Cambridge J Econ, Oxford University Press* 40(5):1397–1420
- Lung, Y (2022) Les monnaies locales dans les dynamiques de transition (Éditions Apogée)
- Magnen JP, Fourel C (2015) D'autres monnaies pour une nouvelle prospérité: mission d'étude sur les monnaies locales complémentaires et les systèmes d'échange locaux, Ministère du logement, de l'égalité des territoires et de la ruralité
- Multilateral Development Banks (2021) Joint statement by the multilateral development banks: nature, people and planet. UN Climate Change conference. <https://ukcop26.org/mdb-joint-statement/>
- Polanyi K (2009) *La Grande Transformation, aux origines politiques et économiques de notre temps*. Gallimard, Paris
- Raiden A, King A (2021) Social value, organisational learning, and the sustainable development goals in the built environment. *Resour Conserv Recycling* 2021:105663. <https://doi.org/10.1016/j.resconrec.2021.105663>. 172ISSN 0921-3449
- Richez-Battesti N, Petrella F, Vallade D (2012) L'innovation sociale, une notion aux usages pluriels: Quels enjeux et défis pour l'analyse? *Innovations* 38(2):15–36
- Rosa JL, Stodder J (2015) On velocity in several complementary currencies. *Int. J. Community Curr. Res.* 19:114–227
- Thérét B, Marques-Pereira J (2007) Dualité monétaire et souveraineté à Cuba. In B Thérét, *La monnaie dévoilée par ses crises*, vol 1, Edition de l'école des hautes études en sciences sociales, 429–461
- Thérét B, Kalinowski W (2012) De la monnaie unique à la monnaie commune. Pour un fédéralisme monétaire européen. Institut Veblen pour les réformes économiques
- Theret B (2015) Vers l'institution de monnaies fiscales nationales dans la zone euro ? Les Possibles 8
- UK Cabinet Office 2012. A guide to SROI. <https://socialvalueuk.org/resource/a-guide-to-social-return-on-investment-2012/>
- Ulanowicz R, Goerner SJ, Lietaer B, Gomez R (2009) Quantifying sustainability: resilience, efficiency and the return of information theory. *Ecol Complex* 6(1):27–36
- UNCTAD, 2020. Trade and Development Report 2020. From global pandemic to prosperity for all: avoiding another lost decade. https://unctad.org/system/files/official-document/trd2020_en.pdf
- United Nations, 2023. High level dialogue on Financing and Development. https://www.un.org/sustainabledevelopment/blog/2023/09/press-release-with-trillions-needed-to-achieve-sustainable-development-goals-world-leaders-gather-to-set-out-bold-solutions-to-urgently-scale-up-investments/?_gl=1*rcca6h*_ga*MjA5OTI4NDg1OC4xNzA0ODkzMjc*_ga_5SEKZKS878*MTcwNDg5MjI3Mi4xLjEuMTcwNDg5MjMwO_C4yNC4wLjA.*_ga_TK9BQL5X7Z*MTcwNDg5MjI3Mi4xLjAuMTcwNDg5MjI3Mi4wLjAuMA. Last accessed on Jan 10th, 2024
- Varoufakis Y (2017) *Adults in the Room. My Battle with Europe's Deep Establishment*. Bodley Head, UK, p 560
- Walter C (2020) Sustainable financial risk modelling fitting the SDGs: some reflections. *Sustainability* 12(18):7789
- World Health Organization (2017) Social return on investment Accounting for value in the context of implementing Health 2020 and the 2030 Agenda for Sustainable Development. Investment for Health and Development Discussion Paper
- Wray R (2012) *Modern Money Theory. A Primer on Macroeconomics for Sovereign Monetary Systems*. Palgrave-Macmillan, London, UK
- Yates BT, Marra M (2017) Introduction: social return on investment (SROI). *Eval Program Plann* 64:95–97. <https://doi.org/10.1016/j.evalprogplan.2016.10.013>
- Zanabria M, Thérét B (2007) Sur la pluralité des monnaies publiques dans les fédérations. Une approche de ses conditions de viabilité à partir de l'expérience argentine récente. *Écon et Inst* 10–11:9–66

Author contributions

Both authors contributed equally to this work.

Competing interests

The authors declare no competing interests.

Ethical approval

Ethical approval was not required as the study did not involve human participants.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

Supplementary information The online version contains Supplementary Material available at <https://doi.org/10.1057/s41599-024-02993-8>.

Correspondence and requests for materials should be addressed to Thomas Lagoarde-Ségot.

Reprints and permission information is available at <http://www.nature.com/reprints>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

© The Author(s) 2024