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How much a dollar cost: Currency hierarchy as a driver of ecologically unequal exchange

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ABSTRACT

Asymmetric transfers of biophysical resources from the Global South to the North are a key obstacle to sustainable development. The underlying causal drivers of this 'ecologically unequal exchange' are not well understood. This paper accounts for the causal role of hierarchy between currencies as one driver of ecologically unequal exchange. Drawing on dependency theory, I propose testable hypotheses that explain why countries that issue internationally acceptable currencies create net inflows of embodied labour, land, energy, raw materials, and carbon from countries whose currencies lack international acceptability: Countries with lower-ranking currencies face higher interest rates, which constrain their policy space, drive income outflows, and necessitate resource exports. Such countries also tend to have lower price levels (measured as the ratio between exchange rates and purchasing power parity rates) because their currencies are not demanded internationally, resulting in reduced dollar income per exported resource. To test these hypotheses, I use a novel categorical operationalization of currency hierarchy. I compare different observable correlations to the theoretical correlations implied by the proposed hypotheses, and test multiple regression models against cross-country data. Overall, the results are consistent with the hypotheses. Considering alternative explanations, the conclusion seems justified that currency hierarchy is a significant driver of ecologically unequal exchange, and that this mechanism operates specifically through cross-country divergences in interest rates and exchange rates. In short, the monetary cost of a dollar impacts the biophysical cost of a dollar.

'How much a dollar really cost: the question is detrimental, paralyzing my thoughts'.

— *Kendrick Lamar, 'How much a dollar cost' (2015)*

1. Introduction

The causes and the consequences of global ecological degradation are distributed unevenly. Not only are low-income regions in the Global South disproportionately affected. Much of their labour, land, raw materials, energy, water, and carbon emissions are used to produce goods for export to high-income regions in the North (Hao, 2020; Dorninger et al., 2021; Althouse, Cahen-Fourot, Carballa-Smichowski, Durand, & Knauss, 2023). This flow of biophysical resources is not reciprocal, as Northern countries tend to export high-tech goods and services that embody relatively lower quantities of such resources.

The 'asymmetric transfer of biophysical resources and socio-environmental impacts' (Hornborg & Martinez-Alier, 2016: 329) has been conceptualized as 'ecologically unequal exchange'. EUE theory maintains that these transfers are driven by a divergence between the levels of monetary compensation that countries receive on average for each unit of biophysical resources embodied in their exports (Hornborg, 2003; Rice, 2007; Frey et al., 2019; Dorninger et al., 2021). Southern countries receive fewer dollars per exported resource than Northern countries, and they receive smaller quantities of the same resources for each dollar they spend on imports. In this biophysical sense, a dollar *costs* more in the South than in the North.

Much empirical research examines the social and economic consequences of EUE (e.g. Austin, 2021; Alonso-Fernández & Regueiro-Ferreira, 2022; Althouse et al., 2023). The precise causal mechanisms through which EUE operates are relatively less well understood. In particular, the literature on its causal drivers almost entirely neglects the role of international power asymmetries in the realm of money and finance. This is a surprising gap, since neighboring research areas are very much concerned with such asymmetries: There is broad agreement

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among scholars of International Political Economy that the structure of the global monetary system is characterized by a 'currency hierarchy' (e.g. Strange, 1988; Cohen, 2000; 2015; Norrlof, 2010; 2014). As one effect of that hierarchy, countries that issue internationally less acceptable currencies face relatively high financial costs if they wish to access internationally more acceptable currencies (Paula, Fritz, & Prates, 2017; Prates, 2020). In this monetary sense, too, a dollar *costs* more at the lower end of the currency hierarchy than at its top.

The conceptual parallels between currency hierarchy and ecologically unequal exchange are as obvious as the research questions that they imply: How are the diverging financial costs of a dollar related to its diverging biophysical costs? What, if any, are the effects of power asymmetries in the international monetary and financial system on the movement of biophysical resources across borders? Does currency hierarchy play a role in causing ecologically unequal exchange, and if so, through which causal mechanisms?

This paper does not provide definitive answers to these questions, but it does propose some novel hypotheses, and tests their plausibility, thereby laying the groundwork for further studies. It examines the effect of currency hierarchies on resource flows, and only briefly (in section 3.5) discusses possible effects in the reverse direction, in particular the possible effects of structural productivity differences on monetary conditions, which can be deducted from the framework of orthodox economics. A final determination of the direction and extent of causal effects is beyond the scope of this article.

To explain how currency hierarchy affects resource flows, I draw on the broader research program of dependency theory. Sections 2.1 and 2.2 review the literature on EUE and currency hierarchy to substantiate the overall hypothesis that the two are causally linked. Section 2.3 proposes two novel causal paths: Currency hierarchy affects (1) interest rates and (2) price levels. Countries that issue internationally acceptable currencies tend to have relatively lower interest rates and higher price levels. These divergences directly affect the average monetary compensation that countries pay and receive for each unit of biophysical resources embodied in their imports and exports, which in turn affects the cross-border flows of these resources. Section 3 presents some tentative evidence in favor of both causal path hypotheses. I operationalize the concepts of EUE and currency hierarchy empirically, I present a set of correlations and multiple regression models whose results support the proposed hypotheses, and I briefly discuss alternative explanations. Section 4 concludes.

2. Theoretical framework and hypotheses

Ecologically unequal exchange and currency hierarchy are two concepts rooted in the broader tradition of dependency theory. The different strands of dependency theory are united by their particular interest in the dynamics of economic polarization under global capitalism (see Kvangraven, 2020; Antunes de Oliveira & Kvangraven, 2023). Dependency theorists typically conceptualize the global economy as a 'world system' comprising a 'core' and a 'periphery' (e.g. Wallerstein, 1974). While peripheries are marked by a specialization in the production of raw materials, cash crops and low-tech industrial manufactures, core regions generate high incomes from the production of high-tech goods and knowledge-intensive services. Consequently, dependency theorists understand capitalist 'development' in the core and 'underdevelopment' in the periphery as two interdependent sides of the same process (e.g. Rodney, 2018 [1973]; Amin, 1977).

Major contributions to dependency theory, especially its more reformist and politically influential currents, come from Latin America. Often working within the *Comisión Económica para América Latina* (CEPAL) established in 1949, structuralist thinkers like Raul Prebisch, Hans Singer, Fernando Henrique Cardoso or Celso Furtado examined the historical dynamics of national disintegration, consumption patterns, and the changing terms of trade as factors hindering the development of Latin America (Kay, 2010: 130-139).

This article mainly draws on two other approaches within dependency theory. On the one hand, scholars in the traditions of Marxism, 'world systems' analysis and, more recently, political ecology regard 'unequal exchange' as a key mechanism of imperialism and uneven development (e.g. Nkrumah, 1965; Rodney, 2018 [1973]; Emmanuel, 1972; Hornborg, 1998; Patnaik & Patnaik, 2016; Patel & Moore, 2017). On the other hand, scholars of 'currency hierarchy' and 'international financial subordination' study the link between power asymmetries in the global monetary-financial system and uneven socio-economic development (e.g. Paula et al., 2017; Bonizzi & Kaltenbrunner, 2020; Alami et al., 2022). However, these two approaches remain mostly disconnected from each other. Scholars of money rarely venture into political ecology, or vice versa.

One notable exception is the work of Romain Svartzman and Jeffrey Althouse, who argue that three structures of hierarchy must be understood as interdependent and mutually reinforcing: First, 'a currency hierarchy which structurally reinforces the Periphery's financial dependence on the Core', second, 'a hierarchy of production […] which concentrates low value-added sectors in the Periphery', and third, 'an ecological hierarchy, constituted by the expansion and intensification of resource- and pollution-intensive activities towards Peripheral frontiers of commodity extraction' (Althouse & Svartzman, 2022:681). Elsewhere, they specify that currency hierarchies are both 'constituted and maintained' by EUE (Svartzman & Althouse, 2020:1). The causal model that they propose involves multidirectional relationships, or even a self-reinforcing causal loop, between currency hierarchy, productive structure, and resource flows. The main contribution of this article is to develop one of the causal paths proposed by Althouse and Svartzman – the effect of currency hierarchy on EUE – into a set of detailed hypotheses that can be empirically tested against quantitative data.

2.1. Ecologically unequal exchange

Ecologically unequal exchange describes a self-reinforcing dynamic whereby peripheries are driven to export large quantities of embodied resources in exchange for less resource-intensive imports from core countries. Such large-scale outflows of resources from the periphery typically lead to persistent poverty, ecological degradation, and political instability, all of which impair peripheral states' capacity to follow a path of autonomous social, political, economic, and technological development (Bunker & Ciccantell, 2005; Rice, 2007; Costantini, Morando, Olk, & Tausch, 2022). Lack of such development and of productivity growth, in turn, reproduces the initital inequality. Core countries, in contrast, can satisfy high levels of domestic resource consumption while offloading onto peripheries the most socially and environmentally destructive effects, such as biodiversity loss (Shandra, Leckband, McKinney, & London, 2009), water pollution (Fitzgerald & Auerbach, 2016), or deforestation (Jorgenson, Dick, & Austin, 2010). Access to cheap biophysical resources also allows core countries to continually further their technological advantage, thereby increasing their factor productivity (Hornborg, 2014). Asymmetric resource transfers and technological disparities thus feed each other, creating a self-reinforcing cycle of global technological and economic divergence, alongside an ecological collapse of planetary scale but very unevenly distributed harm. While EUE is a structural feature of the world system since the early modern period, the volume of asymmetric resource flows has increased in absolute terms over time, especially over the last decades (Dorninger et al., 2021; Hickel, Sullivan, & Zoomkawala, 2021; Rivera-Basques, Duarte, & Sánchez-Chóliz, 2021; Althouse et al., 2023).

At the heart of EUE theory is the argument that unequal biophysical flows are both driven by and hidden behind equal monetary flows. As commodities travel through global production chains, the increase in their monetary price accelerates in relation to the accumulation of ecological costs associated to each production step – in other words, the monetary compensation per embodied resource increases. What is 'unequal' is the ratio between the biophysical quantities of resources that

are used up in each production step, and the quantity of money paid for the product that comes out.[1] Before examining the drivers of EUE, it is useful to formalize these claims on the macroeconomic level.

2.1.1. Formalizing ecologically unequal exchange theory

A country's net balance for a given resource – for example, embodied energy E – can be defined as the total quantity of that resource embodied in its imports, minus the quantity embodied in its exports.[2] The relationship between a country's monetary export revenues and its physical exports of embodied energy is then determined by the average monetary compensation $p_{x,e}$(in current USD) that residents of this country receive for each unit of energy (in kJ) embodied in their exports X.

$$p_{x,e} = \frac{X}{E}$$

The inverse $\frac{1}{p_{x,e}}$ denotes the 'energy cost' of adding one USD worth of value in exports. The net energy balance *NEB* of a country i then depends on the ratio of exports to imports, and on the average monetary compensation per kJ of energy embodied in exports and imports.

$$NEB_i = \frac{M}{p_{m,e,i}} - \frac{X}{p_{x,e,i}}$$

In a simple two-region model where the periphery's exports are equal to the core's imports and vice versa, the net energy balance of the core is given by:

$$NEB_c = \frac{X_p}{p_{x,e,p}} - \frac{X_c}{p_{x,e,c}}$$

Two extreme cases can illustrate the mechanics of EUE: If core-periphery trade is balanced in monetary terms $(X_c = X_p)$, then any deviation between the monetary valuation of embodied energy implies a net energy transfer, i.e. the periphery must expand relatively more resources to achieve a monetary trade balance. In the other hypothetical extreme case, if the monetary valuation of embodied energy is equal $\left(p_{x,e,c} = p_{x,e,p}\right)$, then a trade deficit in the core implies a commensurate net energy transfer from the periphery.

EUE theory focuses not on monetary trade imbalances but on the divergence in monetary valuation. In fact, EUE theorists maintain that such a divergence follows necessarily from the combined principles of capitalist production and of physics (Hornborg, 2003, 2014; Dorninger et al., 2021). Their argument starts from three premises: First, no capitalist would organize production except to produce increase outputs that fetch higher prices than their inputs. Second, according to the second law of thermodynamics, some energy (and, similarly, labour, land, and other resources) must be dissipated in every production process. As a commodity travels through the production chain, more and more resources are dissipated and thus 'embodied' in it. At the same time, its price necessarily increases. Third, crucially, the commodity's price and the energy and resource content do not increase at the same relative rate throughout the production process: In the earlier production steps, the cumulative energy and resources dissipated in production tend to rise faster than the value added to them. In the later steps, the opposite is true. While this is not a law-like necessity that holds across all value chains everywhere, EUE scholars have identified the strong empirical regularity of this general tendency (e.g. Dorninger et al., 2021). Finally, if earlier steps take place in the periphery and later steps take place in the core, it follows that the core receives a higher monetary compensation per unit of resource embodied in its exports than the periphery.

2.1.2. What drives ecologically unequal exchange?

Why does the ratio of value added to resources embodied increase as commodities travel through value chains? The putative causes of this empirical regularity can be further divided into three complementary mechanisms. First, the exports of the core and the periphery are, by definition, composed of different sets of commodities. The current global division of labour has historically been forced upon the periphery in the era of formal colonialism, and it has proven extremely persistent over time (e.g. Frank, 1967; Bunker, 1984; Jorgenson, 2016; Frey et al., 2019; Infante-Amate & Krausmann, 2019; Weber, Semieniuk, Liang, & Westland, 2022). Peripheries simply export types of commodities whose production requires relatively little capital and technology, and therefore relatively high proportions of the remaining production factors: labour, raw materials, energy, land, and other biophysical resources, all while increasing the price of the product by relatively little. In contrast, the core exports 'high value-added' types of goods. The Marxian literature on unequal exchange suggests several underlying drivers of this divergence: Core firms enjoy monopoly power based on advanced technology, highly diversified products, and legally protected intellectual property (e.g. Mandel, 1975; Wallerstein, 2004; Ferraro, 2008; Schwartz, 2009). Peripheral export industries, producing relatively more homogenous commodities, face relatively stronger global competition and thus a higher price elasticity of demand (e.g. Baran & Sweezy, 1966). In a more dynamic framework, Utsa and Prabhat Patnaik (2016) argue that whenever imperialist core countries do face an increase in the prices of imported 'tropical goods', they react by imposing measures to depress incomes in the periphery, so as to again deflate prices. The evolution of structural differences of this type over time is reflected in the terms of trade, which according to classic Latin American dependency theory have a long-term tendency to fall for peripheral countries as growing core countries increasingly demand more industrial goods than raw materials (Prebisch, 1944 and Singer, 1949; for empirical evidence, see Harvey, 2010).

Second, unequal exchange may result from diverging factor productivity (e.g. Amin, 1977). Even under the (counterfactual) hypothesis that core and periphery export the same set of commodities at the same prices, the periphery would still receive relatively lower monetary compensation per unit of embodied resource if it uses relatively less resource-efficient technology to produce those commodities. Certainly, not all export sectors in all peripheral countries have lower efficiency of all input factors (Hickel et al., 2021:1043). Instead, mobile productive capital tends to (re-)locate to sites where overall input costs, although not necessarily the throughput of specific biophysical resources, are minimized. One example is 'carbon leakage' (Babiker, 2005), e.g. the relocation of industrial production to China since circa 2000, driven by the combination of high labour productivity and low wages, regardless of the Chinese energy system's lower carbon efficiency (Malm, 2012).

Third, even if both the set of commodities and the production techniques were globally homogenous, the monetary compensation for each commodity could still diverge if factor prices diverge, for instance if wages are lower in the periphery due to a lower degree of labour organization (Emmanuel, 1972; Hickel et al., 2021).

Each of the three conditions – terms of trade, factor productivity, factor costs – is sufficient to explain the observation that core countries

[1] EUE differs from Samir Amin's classic Marxist definition of unequal exchange as 'the exchange of products whose production involves wage differentials greater than those of productivity' due to the relatively lower wage bargaining power of workers in the periphery (Amin, 1977: 211; see also Emmanuel, 1972). Although such differentials can drive an asymmetric transfer of physical labour time, Marxists usually conceptualize unequal exchange in terms of value. This opens a line of critique by neoclassical economists, for whom any market exchange is, by definition, equal in terms of subjective value, since otherwise it simply would not occur (e.g. Samuelson, 1976).

[2] There is no logically necessary or empirically typical correlation between these biophysical balances and the monetary balances recorded in the balance-of-payments (BoP) statistics: some core countries typically run persistent biophysical *and* monetary deficits (e.g. US, UK), whereas others tend to run monetary surpluses (e.g. Germany, Japan). While much of the periphery tends to run deficits on both accounts, fossil fuel exporters usually run dual surpluses (Moran, Lenzen, Kanemoto, & Geschke, 2013).

persistently receive higher monetary compensation than peripheries for resources embodied in their exports. This causes unequal cross-border net resource flows even if trade is balanced in monetary terms.

However, the conditions are all relatively proximate drivers of EUE that themselves need to be explained. It seems more difficult to tightly identify the underlying long-run causes. For instance, Dorninger et al. (2021) have found clear correlations between EUE and 'economic power' (operationalized as Gross National Income per capita), but ambivalent results for the role of 'military power' (proxied by military expenditure) and biophysical resource endowments, and no correlation to 'technological power' (proxied by a technology adoption index). Their results suggest that there must be other drivers of EUE.

The existing literature clearly neglects the possible role of power asymmetries in the realm of money and finance. For instance, prominent EUE scholars seem to assume that all parties to an international exchange always pay, immediately, in dollars (e.g. Hornborg, 2003:1). If this were the case, trade would always be perfectly balanced in monetary terms, and asymmetric resource transfers would exclusively be the result of diverging monetary compensation per resource. In fact, trade or financial flows are rarely balanced in monetary terms, as international payments are regularly postponed by means of issuing external debt.

Issuing external debt comes at a price – in fact, two prices: the interest rate, and the exchange rate (in its relation to the domestic price level). It may seem quite intuitive that both prices of money should have significant effects on the monetary quantities that countries receive for their exports and pay for their imports. Yet, neither plays a significant role in EUE literature.

This gap renders EUE theory vulnerable to a critique: Orthodox economists would expect that, under conditions of goods and capital mobility, cross-country differences in production factor costs should be neutralized through adjustment in exchange rates or price levels. Empirically, this clearly does not happen, but the EUE literature does not yet try to systematically explain *why* these monetary variables do not adjust to productivity differentials, unequal factor costs or deteriorating terms of trade. The absence of monetary variables in EUE theory is startling, given the literature on currency hierarchy thriving in its immediate intellectual vicinity.

2.2. Currency hierarchy

Mainstream IPE scholars typically conceptualize 'currency hierarchy' as a divergence in the degree to which different currencies fulfil the functions of money (i.e. unit of account, store of value, and means of exchange) on the international level (e.g. Cohen, 2015). In contrast, Latin American dependency theorists in the post-Keynesian tradition (e.g. Kaltenbrunner, 2015; Prates, 2020; Bonizzi & Kaltenbrunner, 2020; Reis & de Oliveira, 2021) draw on Keynes, 1973 [1930]; Keynes, 1964 [1936]: ch. 17) original introduction of the concept of currency hierarchy. They start from the observation that the privilege of issuing the ultimate means of settling international debts – the 'key currency' or 'world money' (Marx, (1976 [1867]): 242) – has always been exclusive to one or a few hegemonic powers. The key currency today is the onshore and offshore US dollar (Murau, Rini, & Haas, 2020). The degree to which any currency is internationally acceptable is determined by the degree to which it is ultimately convertible into dollars (Murau et al., 2022). The result is a pyramidical structure, in which the position of any currency depends on its *liquidity* (Minsky, 1976; Aglietta and Coudert, 2019; Olk, 2024): A liquid currency is one that is convertible into other currencies in large volumes, quickly and without major price movements, and which can therefore be used to meet outstanding financial obligations upon short notice. Relatively liquid debt instruments thus provide those who hold them with more 'potential convenience or security' (Keynes, 1936: 226) in the face of fundamental uncertainty about the future. All else equal, economic agents are therefore willing to hold liquid currencies in relatively larger quantities (Andrade & Prates, 2013; see also Cohen, 2015:21). They also demand a small compensation for holding relatively illiquid currencies, the 'liquidity premium'. Liquidity premia generally tend to increase during periods of heightened uncertainty, but there is also a long-run structural divergence of liquidity premia between currencies: Currencies with more limited or costly access to emergency dollar liquidity from the balance sheet of the Federal Reserve are less liquid even in non-crisis times (Murau et al., 2022).

To attract inflows and prevent outflows of both domestic and foreign finance capital, peripheries must compensate for the relatively lower liquidity premia of their currencies by ensuring higher yields on their liabilities (Andrade & Prates, 2013; Kaltenbrunner, 2015). Consequently, their central banks are forced to set higher domestic interest rates, and to pay relatively high rates on external debt. In addition to their currency's lower liquidity premium, peripheral governments and corporations may also face relatively higher credit risk, not least because the combination of high interest rates, unstable capital flows and volatile exchange rates creates financial and macroeconomic instability (Ocampo, 2009; Kaltenbrunner and Painceira, 2018). These instabilities have generally increased with financial globalization and the deregulation of international capital flows (Prates, 2020; Alami et al., 2022). They limit the capacity of peripheral governments to pursue autonomous monetary, fiscal, and industrial policies (de Paula et al., 2017; Fritz, de Paula, & Magalhães Prates, 2018; Prates, 2020). The key determinant of a government's policy space is its degree of monetary sovereignty (Prates, 2020). Monetary sovereignty is usually defined as the ability of a government to issue money and set the prices of that money within its jurisdiction (Zimmermann, 2013:3; Pistor, 2017). The literature broadly converges on three conditions of monetary sovereignty: First, a state with monetary sovereignty must be able to enforce the use of a unit of account, predominantly by raising taxes in it (Bell, 2001; Tcherneva, 2006). Second, monetary sovereignty requires a floating exchange rate, no public debt denominated in foreign currency, and no convertibility into gold (ibid.). Third, a government's ability to create money without causing inflation or financial instability hinges directly on its capacity to regulate private actors that create credit in the same unit of account (Murau & van't Klooster, 2022). Monetary sovereignty complements liquidity as the second key dimension of currency hierarchy, especially at its lower levels (Prates, 2020).

In summary, peripheries are typically characterized by incomplete monetary sovereignty, and their currencies by low liquidity. Economic actors are, ceteris paribus, less willing to hold them than the currencies issued by core countries. This has direct effects on the cost that peripheries face if they seek access to foreign currency, and therefore on their trade balance and the development paths open to them.

2.2.1. Between exorbitant privilege and original sin

The problem of funding economic and political development is not a shortage of money as such, but specifically of foreign exchange (Oberholzer, 2023). Any country, except under conditions of complete autarky, is subject to a balance-of-payments (BoP) constraint: its development is predicated on its ability to fund imports of essential goods, such as machines, food, energy, or pharmaceuticals (Amin, 1977; Thirlwall, 1979; Kvangraven, 2021; Loescher, 2023).

Most imports are billed in foreign currency, especially the goods typically imported by peripheries. For example, all but the largest countries in Latin America and Asia conduct more than 80 % of their trade in USD; and except for 10 core countries, no country uses its own currency in more than 15 % of its trade (Boz et al., 2021, Appendix). Countries must also constantly acquire dollars to settle their outstanding dollar-denominated debts, and their central banks must accumulate dollar (or euro or yen) reserves to stabilize exchange rates and guard against capital outflows. Without previously accumulated reserves or foreign aid inflows, there are four ways to do this: residents may generate primary income (primarily from investment abroad), create inflows on financial account (by borrowing from foreigners) or capital account (by selling real assets to foreigners), or they may generate export revenues.

The cost of sustaining current account deficits by issuing external debt (option two) varies along the currency hierarchy. Those at the higher end can borrow in their own currency – they enjoy an 'exorbitant privilege'. The liabilities of a country thus privileged are demanded by foreigners not just as a means of paying for the country's exports, but also as safe assets, i.e. as a store of value (Kirshner, 2008; Eichengreen, 2011). That additional demand pushes interest rates on their external liabilities below the rate of return on their external assets, generating net income flows over time (McCauley, 2015).

At the lower end of the currency hierarchy, peripheries face relatively high costs of borrowing from foreigners. Such countries often resort to issuing external debt denominated in foreign currencies, committing the 'original sin' (e.g. Eichengreen et al., 2023), which limits their monetary sovereignty and thus their development capacity (Paula et al., 2017). Some countries may improve their position by accessing dollars through offshore financial markets (Binder, 2022; Kohler, 2022), but overall, financing current account deficits through financial account surpluses is relatively more costly for peripheral than for core countries: high yields on liabilities and low returns on assets drive net income outflows from the periphery over time.

Consequently, peripheral countries must pursue the remaining options to a relatively greater extent: transferring real assets abroad or running trade surpluses. Both choices tend to involve net outflows of biophysical resources: Generating inflows on capital account mainly involves the sale of rights to land, subsoil minerals, water, forests, or other natural resources (IMF, 2009:81). Such transfers of ownership typically imply future transfers of resources abroad. Finally, although a negative trade balance as such does not necessarily imply a negative biophysical balance, ceteris paribus an increase in exports relative to imports implies an increase in net resource outflows. In short, peripheries must 'specialize in the exploitation and exportation of nature in order to access core currencies' (Svartzman & Althouse, 2020: 9).

2.3. Two prices of money as drivers of EUE

A clear picture emerges from the literature reviewed so far: Countries with lower-ranking currencies experience higher net income outflows than they would in a world without currency hierarchy; they must export larger quantities of biophysical resources to balance their external accounts; and they cannot borrow as many dollar. As counterfactuals, these claims are difficult to test empirically. They also refer to quantities that are difficult to measure and compare across countries. However, we can expect such divergences in quantities that result from currency hierarchy to be reflected in two much more easily observable and comparable prices: interest rates and price levels. As the remainder of section two will explain, these can serve as mediator variables, and thereby as proxies for the causal paths that lead from currency hierarchy to ecologically unequal exchange.

2.3.1. Unequal interest rates and financial subordination

The long-run level of interest rates has various effects on exports, imports, the monetary compensation of resources, and on the long-term development of the economy's productive structure.

Relatively high interest rates turn peripheral economies into a prime target for large portfolio investment flows, responding to short-term interest rate arbitrage opportunities (World Bank, 2023). These capital flows are typically unstable, thus causing exchange rate volatility, which peripheral central banks reduce through interventions that require them to accumulate foreign reserves (Harvey, 2002; Prates, 2017). Exchange rate volatility also creates an incentive to invoice trade in dollars. Changes in the international liquidity preference tend to cause sudden outflows of capital to more liquid currencies (Bortz and Kaltenbrunner, 2018). Both effects further aggravate the BoP constraint. The lack of stable funding also inhibits the planning, funding and execution of long-term projects and development strategies focused on high value-added production or resource efficiency. Volatility discourages the long-term investment of 'patient' capital necessary for climbing up global value chains (Chang, 2003; Schwartz, 2009; Mazzucato, 2015; Ivashina & Lerner, 2021), let alone for shifting to more sustainable production techniques (Svartzman & Althouse, 2020). Instead, peripheries are generally led to develop short-term export-led strategies for products with low added value. The short-term export-led development model places peripheral states in direct competition with one another (Vernengo, 2006; Schwartz, 2009). This competition and the tension between unstable export revenues and the constant need to service foreign-denominated debt creates strong incentives for governments to deregulate the most profitable export sectors, which tend not to be the most ecologically sustainable (Culas, 2006). On the level of individual firms, the pressure to quickly achieve high rates of return favours extractivist and exploitative business models (Pettifor, 2020:138; see also Marx, 2013 [1867]:834). On the macroeconomic level, high levels of foreign-denominated debt create pressure to achieve high rates of capital accumulation and economic growth in the short term (Hartley & Kallis, 2021; Cahen-Fourot, 2022), with all the ecological pressures associated to growth (Hickel & Kallis, 2020).

On the state level, high yields on public debt and high shares of foreign-denominated debt (the 'original sin') limit peripheral governments' space for monetary, fiscal, social, industrial and exchange rate policies that would be conducive to forms of economic development that are less based on resource-intensive exports to the core (Prates, 2020; Fritz et al., 2018). Interest rate hikes in the core force the periphery to follow suit, lest it experience a 'sudden stop' of capital inflows and thus BoP and debt crises, in particular in countries with large foreign-denominated debt (Vernengo, 2006, Fritz et al., 2018; Prates, 2020; Alami et al., 2022). Since the late 1970s, such crises have forced many peripheral states to accept loans from the International Monetary Fund with 'structural adjustment' conditions attached that require deflationary measures, including public austerity, wage suppression, and resource extractivism (Kretzmann & Nooruddin, 2005; Culas, 2006), with often devastating effects on social and environmental indicators (Shandra et al., 2008; 2010; Federici, 2010; Kentikelenis, Stubbs, & King, 2016; Thomson, Kentikelenis, & Stubbs, 2017) and on the terms of trade (Patnaik & Patnaik, 2016).

Many peripheral states have inherited colonial banking systems that are biased towards short-term finance rather than long-term investment, and dependent on global banks for access to dollar liquidity (Swoboda, 1968; Amin, 1977; Koddenbrock, Kvangraven, & Sylla, 2022). High interest rates compress the 'elasticity space' (Murau et al., 2022) and lead to 'credit repression' (Koddenbrock et al., 2022) in the periphery, providing the relatively less constrained foreign banks with a clear competitive advantage. As one direct consequence, financial services make up a relatively large share of the imports of 'financially subordinate' countries, but a relatively low share of their exports. Financial services have relatively low direct ecological costs but make up a considerable share of the core's exports. For this reason alone, peripheral exports include a higher share of relatively resource-intensive goods than core countries with large financial industries (and offshore financial centres). In addition, diverging interest rates and underdeveloped peripheral credit systems increase the bargaining power of corporations from core countries, providing them with direct opportunities to extract value and resources from peripheral exporters by way of 'early payment' arbitrage: core importers can borrow dollars cheaply, offering peripheral exporters early payment in return for lower prices, since those exporters face higher interest rates domestically, and therefore value early payment more highly. An early example of this is the 17th century Dutch-Baltic grain trade (Wallerstein, 1974:122) that provided a key material basis for European colonial expansion under Dutch hegemony (Moore, 2010).

The reliance on foreign funding and the interest rate differentials causes persistent income flows from peripheries to the core. Peripheral countries tend to hold safe, long-term, low-yield assets, while incurring riskier, short-term, high-yield liabilities (UNCTAD, 2019:120). Core

countries, especially key currency issuers, do the opposite: They transform low-yield long-term liabilities into high-yield short-term assets, effectively acting like banks and generating positive primary income flows (Cohen, 2015:52; see also Kindleberger, 2019 [1965]) that tilt the current account balance in favor of core countries and thus, all else equal, necessitate higher peripheral exports.

The most important longer-term source of funding for peripheries is foreign direct investment (FDI). While often leading to economic growth in the short to medium run, FDI is biased towards carbon-intensive and ecologically destructive sectors (Chowdhury, Shanto, Ahmed, & Rumana, 2020; Jorgenson, 2016). Over time, these investments also create a direct reflux of primary income in the form of profits to the core (Amin, 1977: 200; Sylla, 2023), mostly via offshore financial centres (Binder, 2023a; Garcia-Bernardo, Fichtner, Takes, & Heemskerk, 2017; Soares De Oliveira, 2022). FDI also enables multinational corporations to channel money out of the periphery through tax evasion, intellectual property fees, and transfer pricing (e.g. Garcia-Bernardo et al., 2023; Hickel, 2017:ch.7; Schwartz, 2019), which however are not consistently recorded in the official statistics (Zucman, 2013; Tørsløv, Wier, & Zucman, 2023). Hidden or not, outflows of primary income ceteris paribus mean higher net exports of embodied resources (Nkrumah, 1965; Amin, 1977; Hickel, 2017; Koddenbrock et al., 2022; Alami et al., 2022).

Summing up all these effects, a more general hypothesis can be formulated: Countries with lower-ranking currencies tend to have higher interest rates, and high interest rates lead to net resource outflows by increasing the ratio of exports to imports (via the cost and size of external debt and net income flows), by favoring a composition of exports with relatively high contents of biophysical resources per unit of monetary compensation (via limited elasticity and policy space), and by directly reducing the monetary compensation per exported resource (by reducing the bargaining power of peripheral exporters competing with each other for dollars). The first causal hypothesis that diverging interest rates drive EUE is concrete and testable.

2.3.2. *Unequal exchange rates*

The second causal hypothesis starts from the observation that market exchange rates empirically deviate from purchasing power parity (PPP) rates. PPP rates measure the ratio between two countries' PPP deflators, calculated as the price in USD of a homogenous basket of goods and services. The relative price level in two countries is given by the ratio of the PPP rates to their market exchange rates. If, say, Bolivia's PPP conversion factor is 4 times Switzerland's, and if the BOB/CHF market exchange rate is 1/ 8, then the Swiss price level is twice that of Bolivia. For instance, 100 Swiss Franc can pay for a representative basket of goods in Switzerland, or, if exchanged into Bolivianos, for two such baskets in Bolivia.

Empirically, price levels tend to be higher in countries that issue higher-ranking currencies, and lower in countries with lower-ranking currencies. The causal mechanism that may explain this correlation is laid out in more detail and subjected to an empirical test elsewhere (Olk, 2023). The argument is based on a novel interpretation of the 'exorbitant privilege', whose conventional interpretation states that higher-ranking currencies with high liquidity premia are demanded as an international means of payment and store of value to a relatively greater degree than lower-ranking, less liquid currencies. Now, economists generally agree that a currency's exchange rate depends on the total demand for that currency and its relation to demand for other currencies. In contrast, the PPP rate depends only on the demand for the currency as a means of payment for those goods that can be bought with it in domestic markets, and the quantity of those goods. High-ranking currencies are demanded as a store of value and a means of paying for goods internationally, while low-ranking currencies are only demanded as a means of paying for goods domestically. Such excess demand for high-ranking currencies pushes their exchange rate above their PPP rate, whereas lack of international demand pushes the exchange rate of low-ranking currencies below their PPP rate. The effect should be strongest for countries whose currencies are used internationally as a store of value in large proportions relative to their GDP, but which are not created offshore to a substantial degree, one salient case being Switzerland. There is also supporting evidence from local barter markets using complementary currencies that are virtually not used for saving: Such markets tend to have relatively low price levels, in line with this hypothetical causal mechanism (Olk, 2024).

Marxian scholars of unequal exchange like Gernot Köhler (1998) or Andrea Ricci (2021) have noted that any devation between exchange rates and PPP rates suffices to cause an unequal exchange of labour (see also Somel, 2003; Reich, 2007; Elmas, 2009; Hickel et al., 2021). An agent who has dollars can buy more of a given good if she converts her dollars into a peripheral currency and buys from the periphery. If she can create or access dollars relatively more cheaply than the exporters in the periphery, this monetary privilege enables her to generate an asymmetric net inflow of undervalued embodied resources. Conversely, the international purchasing power of high-ranking currencies is overvalued relative to their domestic purchasing power. Against this backdrop, 'structural adjustment' policies aimed at depreciating peripheral currencies to boost exports clearly exacerbate unequal exchange (Patnaik & Patnaik, 2016).

In summary, the second hypothesis states that EUE is driven partly by diverging price levels, i.e. the deviation between exchange rates and PPP rates. Moreover, this hypothesis involves a novel explanation for this divergence, based on currency hierarchy: A high liquidity premium pushes the market exchange rate above the PPP rate that would equalize the currency's purchasing power across countries. This deviation affects the real price of resources embodied in exports, which in turn affects resource flows.

Of course, this effect only applies *directly* to tradeable goods priced in local currency; but it applies indirectly to all goods whose production requires *factors* priced in local currency. More generally, EUE could also occur if market exchange rates did not deviate from PPP rates; but if they do deviate, some part of EUE must be arising from that deviation, a fact that EUE theory has not yet acknowledged.

The theoretical argument presented in this section is subject to at least two important limitations (see also Olk, 2023): Strictly speaking, using PPP rates as an empirical measure for the exchange-rate driven component of EUE requires the assumption that the average prices of all tradeable goods and of the goods in the PPP deflator basket are the same; and further, that tradeable goods are homogenous across countries (see also Hickel, Dorninger, Wieland, & Suwandi, 2022). Clearly, some raw materials simply are not available in core countries – which is, after all, one possible cause of EUE (Patnaik & Patnaik, 2016) – and some high-tech goods are not available in the periphery (see also section 2.1.2). This fact complicates the measurement of price levels, and may lead to a small over- or underestimation of their effect on EUE (Hickel et al., 2021:1043). Finally, it is worth noting that the Balassa-Samuelson (BS) hypothesis (Balassa, 1973) offers an alternative explanation for diverging price levels (a point to which section 3.5 will return), but it does not negate the central claims of EUE theory as such (see Hickel et al., 2021:1043, contra Subasat, 2013).

With these considerations in mind, four concrete hypotheses about the effect of currency hierarchy on ecologically unequal exchange can be formulated: Net resource flows are driven among other factors by the divergence in monetary valuation of resources embodied in exports, which in turn are affected by currency hierarchy (hypothesis one). This relationship is mediated by two factors: diverging interest rates

(hypothesis two) and diverging price levels (hypothesis three). Overall, these two factors can together explain a significant part of the global divergence in monetary valuation of resources (hypothesis four). The next section offers some simple, preliminary empirical tests of these four hypotheses.

3. Empirical evidence

The overall goal of this article is to generate testable hypotheses, not to test them comprehensively. Nevertheless, any hypothesis should be swiftly rejected if it is obviously inconsistent with the available data. To substantiate the plausibility of the proposed hypotheses, the concepts in them must first be operationalized as observable variables. That is relatively straightforward for the quantities and prices of resources and money, but less so for the concept of currency hierarchy.

3.1. Measuring EUE and the prices of money

The dependent variables in hypotheses one and four are net resource flows and the average monetary compensation that a country receives for each unit of resources embodied in its exports. Embodied resource flows can be estimated based on sector-specific international trade flows, based on the typical biophysical composition of sectoral outputs. Dorninger et al. (2021) calculate net resource flows from the environmentally extended multi-regional input–output table *Eora26*. They provide data for 2015 on 180 countries' net imports of embodied energy, land, labour, and raw materials, as well as the monetary compensation they receive per resource exported. 'Embodied resources' are all the resources that have been used at any point in the production of intermediate goods that go into final exports (Simas, Wood, & Hertwich, 2015; Owen et al., 2017; Bruckner, Fischer, Tramberend, & Giljum, 2015; Schaffartzik et al., 2017). In addition, net imports of embodied carbon emissions can be calculated for 113 countries by subtracting national production-based from consumption-based emission accounts (Andrew & Peters, 2023). To calculate the average monetary compensation per resource exported, Dorninger et al. (2021:4) divide the 'Trade in Value Added' (TiVA) embodied in exports by the resources embodied in the same exports. TiVA measures the total value added by all production steps within a country, and is calculated from *Eora26* as well. TiVA per resource is a close approximation of resource productivity in export sectors.[3]

Measures for the prices of money are readily available: Data for interest rates, market exchange rates and PPP rates can be drawn from the World Bank's 'World Development Indicators' (2016) and International Monetary Fund's 'International Financial Statistics' (IFS), respectively. Table A in the Appendix gives an overview of all data sources and the respective sample sizes. Peripheral countries are generally more likely than core countries to have missing data than core countries, but the number of missing observations is small and unlikely to impair the results. Small offshore financial centers are excluded from the analysis, as they occupy an exceptional position in the global monetary system; and their records in the official monetary statistics are generally inadequate (Binder, 2023a, Tørsløv et al., 2023), and many have inflated per capita resource consumption figures (presumably because foreign consumers are not counted as *capitae)*.

3.2. Measuring currency hierarchy

There is not yet a systematic attempt to measure the position of different countries in the global currency hierarchy. Theorists of currency hierarchy have proposed a categorical classification of currencies, but they classify actual countries and currencies only anecdotally (e.g. Cohen, 2015:15; Prates, 2020: 507). Benjamin Cohen proposes a categorization based on each currency's share in global cross-border trade and finance, but these shares are extremely unevenly distributed. For instance, the top five currencies consistently make up between 80 % and 95 % of all recorded trade, foreign exchange transactions, official reserves, and international banking and debt securities markets, with the USD hovering around 60 % in most of these categories (Cohen & Benney, 2014; Bertaut, Curcuru, & von Beschwitz, 2023). Cohen's 'currency pyramid' thus offers relatively little insight on the relative positions of lower-ranking currencies. The same problem afflicts existing efforts to create composite indicators from quantitative variables (e.g. Chinn & Frankel, 2008; Norloff, 2010).

Instead, the theoretical framework presented in section 2.2. can be operationalized as a qualitative classification of all currencies into categories based on their relative liquidity and monetary sovereignty. Liquidity can be approximated by a combination of the international foreign exchange market size (in line with Cohen, 2015:9) and the degree of access to emergency dollar liquidity from the Federal Reserve through central bank swap lines (following Murau et al., 2022).[4] The degree of monetary sovereignty, which tends to become a more relevant constraint towards the lower levels of the hierarchy, can be operationalized based on the three conditions outlined in section 2.2.1 (see also Prates, 2020). By way of a simple questionnaire, currencies can then be ordered into six categories that, like Cohen's categories, partly borrow their names from the social classes of ancient Rome (see Table 1).

This classification algorithm is applied to 161 countries, using data for 2015 on foreign exchange turnover (BIS, 2015), exchange rate regimes (IMF, 2016), central bank swap lines (Murau et al., 2022), foreign-denominated external debt (Kose, Kurlat, Ohnsorge, & Sugawara, 2022), and a variety of sources pertaining to the currencies' domestic use. The algorithm has been applied independently by two researchers to ensure inter-rater reliability. The results, reported in Table B in the Appendix, echo Cohen's 'currency pyramid' image, with few currencies at the top

Table 1
Classifying national currencies.

	Question	If yes:
Liquidity	Is this currency the US dollar?	*Top*
	Does the central bank issuing this currency have access to the Fed via a C6 swap line *or* is it among the 10 most traded currencies?	*Patrician*
	Does the central bank issuing this currency have access to the Fed via a C14 swap line *or* is it among the 20 most traded currencies?	*Elite*
	Is this currency listed in the Triennal Central Bank Survey of foreign exchange markets?	*Plebeian*
Monetary sovereignty	Is some foreign currency used in this country *or* is more than 95 % of its external debt denominated in foreign currency?	*Permeated*
	Is this currency pegged *or* in a currency board *or* does the state not spend and tax in this currency *or* is another currency used generally?	*Pseudocurrencies*

[3] This is also observable empirically: TiVA per labour hour embodied in exports is so closely correlated to labour productivity (data from Ilo, 2024) across countries that a regression model predicts a 1.5% increase in the TiVA/hour for every 1% increase in labour productivity with an adjusted R-square value of.82 ($p = .01$).

[4] Liquidity premia can also be detected small divergence in the prices of money that should otherwise be established by arbitrage, such as the deviation from interest rate parity (e.g. Lavoie, 2003; Mehrling & Neilson, 2014), but the data required for these calculations is not available for all currencies (see also Olk, 2023).

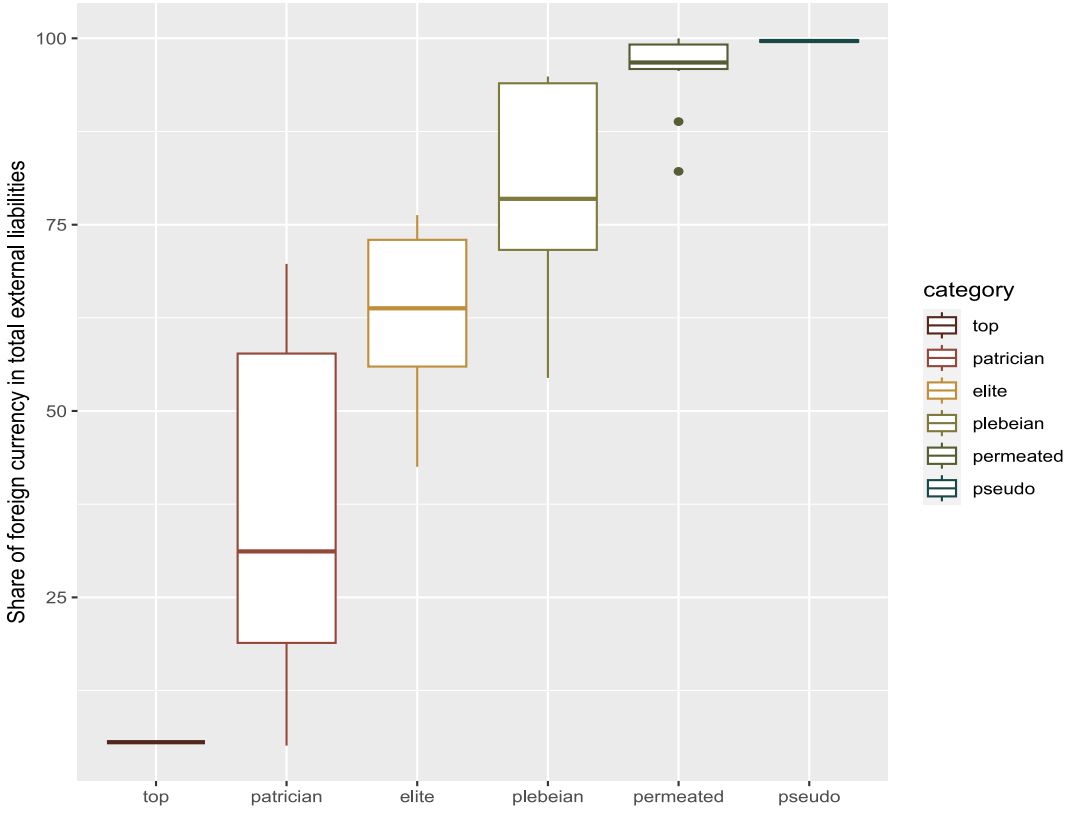

Figure 1. Correlation between currency categories and 'original sin'.

and many at the bottom.

The literature on 'original sin' and 'exorbitant privilege' (see section 2.2.) suggests a useful quantitative robustness check for this qualitative classification. Figure 1 shows a correlation between the share of foreign currency in a country's total liabilities to foreigners (data from Kose et al., 2022) and its position in the currency hierarchy (Spearman rank correlation coefficient = .8547722, p = 0.00), with the limitation that data is not available for most pseudo-currency countries. The categories seem to be an adequate operationalization of currency hierarchy.

3.3. Method

The hypotheses derived in section two can be subjected to a simple empirical test. Each hypothesis implies a specific set of correlations. The first three hypotheses, disassembled into their logical components, imply the correlations listed in Table 2 below.

Wherever these correlations cannot be observed, the corresponding hypotheses should be rejected. Concretely, a strong effect of currency categories (an ordinal variable)[5] on the continuous response variables would imply Spearman rank correlation coefficients close to one (see Artusi, Verderio, & Marubini, 2002). The same method can be applied to identify correlations between the prices of money and the EUE variables.

Whenever the necessary statistical conditions are met, the relationship between these continuous variables can also be formulated as linear regression models. Model M1 operationalizes the essential EUE hypothesis by testing whether the average monetary compensation p_{bxi} of the biophysical resource b embodied in the exports x of country i can predict the net imports M_b, leaving a residual error ε.

$$M_{b,x,i} = \alpha_{b,1} + \beta_1 p_{b,x,i} + \varepsilon_{i,1} \quad \text{M1}$$

Regression models M2 and M3 test hypotheses 2.2 and 3.2, i.e. whether interest rate r and, respectively, the price level ratio of market exchange rate to PPP rate $\frac{S_i}{PPP_i}$ can predict the log of monetary valuation. The log is used here to ensure an approximately normal distribution of the regression residuals.

$$log(p_{b,x,i}) = \alpha_{b,2} + \beta_2 r_i + \varepsilon_{i,2} \quad \text{M2}$$

$$log(p_{b,x,i}) = \alpha_{b,3} + \beta_3 \frac{S_i}{PPP_i} + \varepsilon_{i,3} \quad \text{M3}$$

To represent the overall argument, an additional hypothesis 4.1 can be

Table 2
Theoretically expected correlations.

Hypotheses	
EUE	Countries with higher TIVA per resource exported have higher net resource imports
1.1.	Countries with higher-ranking currencies have higher TIVA per resource exported
1.2.	Countries with higher-ranking currencies have higher net resource imports
2.1.	Countries with higher-ranking currencies have lower interest rates
2.2.	Countries with lower interest rates have higher TIVA per resource exported
2.3.	Countries with lower interest rates have higher net resource imports
3.1.	Countries with higher-ranking currency categories have a higher price level
3.2.	Countries with a higher price level have higher TIVA per resource exported
3.3.	Countries with a higher price level have higher net resource imports

[5] Alternatively, the currency types can also be treated as a non-ordinal categorical variable. In that case, a Kruskal-Wallis rank sum test (KW) can test if the mean values of the response differ between the categories (Ostertagova et al., 2014). They do for many, but not all, response variables: interest rates, price levels, net imports of energy and of carbon, TiVA per land and raw material exports. The results are broadly consistent with those from the Spearman correlation tests. ANOVA is not possible here because the variance in the response variable is not sufficiently similar across categories, as judged by Levene's test (Schultz, 1985).

modelled as a multiple regression M4.1 that includes both predictors:

$$log\,(p_{b,x,i}) = \alpha_{b,4} + \beta_4\, r_i + \beta_5 \frac{S_i}{PPP_i} + \varepsilon_{i,4} \qquad \text{M4.1}$$

For further scrutiny, hypothesis 4.2 includes per capita gross national income (GNI) as a control variable. Not only may it seem intuitively plausible to suspect that any apparent effect of monetary variables on EUE really arises from differences in national income. In the econometric analysis of Dorninger et al. (2021), GNI per capita is also the only explanatory variable that is consistently correlated to EUE. Including per capita GNI *y* as a control variable yields model M4.2:

$$log\,(p_{x,b,i}) = \alpha_{b,5} + \beta_6\, r_i + \beta_7 \frac{S_i}{PPP_i} + \beta_8\, y_i + \varepsilon_{i,5} \qquad \text{M4.2}$$

All models are tested against cross-country data for 2015. Each model is tested separately for embodied energy, land, labour and raw materials and carbon emissions. Given the available data, only hypotheses 1.3, 2.3, and 3.2 can also be tested for embodied carbon emissions.[6]

3.4. Results

Figure 2 plots per capita net imports of resources against TiVA per resource exported, along with linear OLS regression lines from model M1. The correlations are consistent with the basic EUE hypothesis.

Table 3 reports the Spearman correlation coefficients corresponding to hypotheses one to three and the baseline EUE hypothesis. All coefficients have the expected positive sign, and the associated t-tests are all significant ($p < 0.05$), so the null hypothesis that the coefficient is zero can be rejected in all cases.

Overall, the results are more or less consistent with all hypotheses. The effect of currency hierarchy on EUE seems to be most pronounced for embodied labour, and somewhat weaker for energy and carbon emissions.

Figure 3 illustrates the correlations corresponding to hypotheses 1.1 and 1.2 as box plots. The position of a country in the global currency hierarchy is generally correlated with its position in the hierarchy of EUE. Interestingly, some countries with low-ranking currencies have lower net exports of embodied labour than countries in the middle ranks, perhaps because the latter tend to be more integrated in global markets.

Turning to hypothesis 2.1, interest rates are evidently higher in the periphery of the global monetary system than in its core, as Figure 4 shows. Countries in a peg or currency board ('pseudo currencies') are the exception, possibly because their 'elasticity space' is subject to such strong external constraints that their central banks can maintain relatively looser monetary policy.

Moreover, Figure 5 shows correlations between the policy interest rate, net imports, and the monetary valuation of resources, although mostly with high unexplained variance (and hence low R^2 values). Regression lines are included for all cases where M2 is significant. These results support hypotheses 2.2 and 2.3. They hold, with minor variations, also for the lending rate (see Table C in the Appendix).

In line with hypothesis 3.1, countries with higher price levels (a high ratio of exchange rates to PPP rates) occupy the upper levels of the currency hierarchy (see Figure 6). Switzerland indeed has the highest price level of all. Once more, countries in a peg or currency board are the exception, with unexpectedly higher price levels than permeated currencies. One possible explanation is that these currencies' exchange rates are not driven by market dynamics, and that the argument of section 3.2 demand does not directly apply to them.

Price levels are also clearly correlated with EUE, supporting hypotheses 3.2 and 3.3. For net imports of land and energy, the correlations shown in Figure 7 are not tight enough to become significant in the regression model M4, but they are quite strong for labour and raw materials, and for the monetary valuation of all four resources (see also Table C).

The overall proposition is that differential interest rates and price levels together drive international divergences in the valuation of embodied resources (hypothesis 4.1), regardless of the GNI per capita (hypothesis 4.2). Table 4 reports the unstandardized coefficient estimates of the corresponding log-linear OLS regression models M4 and M5. An increase in the predictor variable by the value of the estimator corresponds to a 1 % increase in the TiVA per exported resource.

The available cross-country data for 2015 does not stand in obvious conflict with any of the hypotheses proposed in section 2. There are clear correlations between currency hierarchy, interest rates, price levels, and the net flows of five biophysical resources (embodied energy, land, labour, raw materials, and carbon emissions), as well as with their average monetary compensation. Overall, these results fail to reject the proposed causal hypotheses.

3.5. Limitations, reverse causality, and further research

Correlations, of course, can never validate causal hypotheses. Correlations may result from unobserved causal factors, as in the case at hand the large incidence of unexplained variance (reflected in low R^2 values) indeed suggests. Such factors may include long-standing asymmetries in technology, diplomatic or military power, and they are likely to interact in complex ways with currency hierarchy, interest rates and price levels.

More importantly, the observed correlations would also occur if the causal arrows that connect currency hierarchy, interest rates, exchange rates and EUE actually point in the reverse direction, or in both directions at once – that is, EUE could be the root cause of divergences in interest rates, price levels, and currency hierarchy.

In fact, these explanations might seem quite intuitive to orthodox economists. In particular, they would regard differences in factor productivity as the cause, not the effect, of diverging interest rates and price levels. They would agree with EUE theorists that countries with lower factor productivity in the tradeable goods sector should tend to be net exporters of resources. They would, however, add that the periphery's relatively lower productivity in export sectors also explains why exchange rates don't converge to PPP rates: this is the Balassa-Samuelson hypothesis (BS).[7] Economists might also argue that the higher population or productivity growth of peripheral countries (the latter driven by upward convergence from their lower productivity levels) leads them to have a higher 'natural interest rate' (NIR), and hence higher real rates (e.g. Holston, Laubach, & Williams, 2017).

It is worth considering some empirical and theoretical shortcomings of both the BS and NIR hypotheses. The BS hypothesis not only rests on questionable assumptions about the degree of competition in labour and goods markets (Bordo, Choudhri, Fazio, & MacDonald, 2017). It is also not obvious that the periphery, although having lower overall productivity, should be *disproportionately* inefficient in its export sectors, which in many cases employs foreign-owned capital goods and harshly Taylorist labour regimes (Hickel et al., 2021:1043). In fact, the BS hypothesis yields quite mixed empirical results (Loach, 2001; Choudhri &

[6] The entire dataset and the *R* code for all analyses and plots are available upon request.

[7] The BS hypothesis states that the purchasing power of the core's currency is higher because of the particularly high productivity of its export sector. If the difference between the productivity of the core and the periphery in those sectors that produce tradeable goods is greater than the productivity difference for non-tradeable goods and services, and if wages equal marginal productivity in the export sector, then all wages, and consequently the general price level, will be higher in the core than in the periphery (Balassa, 1964; Samuelson, 1964).

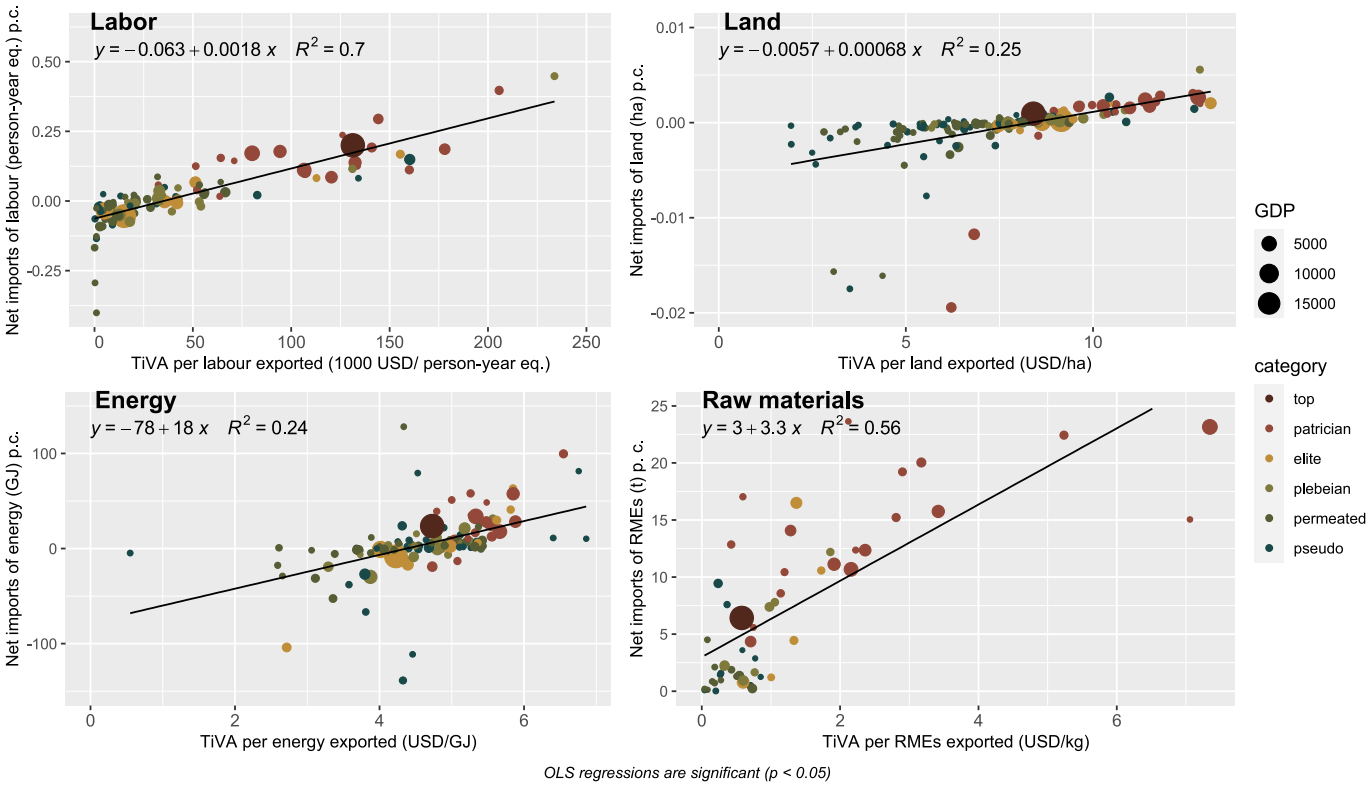

Figure 2. Correlations: Ecologically unequal exchange.

Table 3
Observed Spearman rank correlation coefficients.

Hypotheses		Land	RMEs	Labour	Energy	Carbon
1.1.	Higher-ranking currency → higher TIVA per resource	0.50	0.55	0.48	0.30	
1.2.	Higher-ranking currency → higher net resource imports	0.35	0.39	0.47	0.23	0.27
2.1.	Higher-ranking currency → lower interest rate	0.36				
2.2.	Lower interest rate → higher TIVA per resource	0.51	0.53	0.79	0.59	
2.3.	Lower interest rate → higher net resource imports	0.40	0.40	0.53	0.28	0.38
3.1.	Higher-ranking currency → higher price level	0.44				
3.2.	Higher price level → higher TIVA per resource	0.51	0.65	0.81	0.48	
3.3.	Higher price level → higher net resource imports	0.35	0.37	0.79	0.38	0.42
EUE	Higher TIVA per resource → higher net resource imports	0.84	0.62	0.88	0.70	

Schembri, 2010). Some studies question the presence of a significant Balassa-Samuelson effect for, among others, OECD countries (Gubler & Sax, 2019); Mexico (López-Marmolejo, Ventosa-Santaulària, & Diaz Muro, 2023); Central Europe (Mihaljek & Klau, 2004), Eastern Europe (Égert, Drine, Lommatzsch, & Rault, 2003), Asia (Ishaq, Ghouse, & Bhatti, 2022), and the periphery in general (Hassan, 2016). At the same time, most empirical evidence in support of the hypothesis typically identifies a positive relationship between export sector productivity *growth* and real exchange rate *appreciation* (e.g. Bahmani-Oskooee & Rhee, 1996; Iyke and Odhiambo, 2017; Hussain & Haque, 2020), i.e. co-movements in the variables' rate of change, not their structural cross-country level divergence. Finally, many studies conclude that BS effects are "clearly not the sole cause of deviations from PPP" (Thomas & King, 2008: 139; see also Égert et al., 2003; DeLoach, 2001; Bordo et al., 2017). Since this paper's hypothesis two offers a novel explanation of the failure of PPP, future research should examine its explanatory power in combination with BS effects.

A salient orthodox explanation of diverging interest rates would draw on the theory of the 'natural interest rate' the short-term real rate consistent with optimal output and constant inflation (Wicksell, 1936). The theory is difficult to operationalize and highly contested even in the economic mainstream (Laubach & Williams, 2003). In simplified form, it states that real interest rates are ultimately determined by the demand for and supply of savings, which in turn depend mainly on productivity growth and demographic changes (Holston et al., 2017; Cesa-Bianchi, Harrison, & Sajedi, 2022). Not only does the hypothesis rest on the empirically dubious 'loanable funds' assumption (Pilkington, 2014; Lavoie, 2018). There is also strong evidence that real rates do not depend on demography or productivity growth (Lunsford, 2017; Borio, Disyatat, Juselius, & Rungcharoenkitkul, 2022). Another salient explanation of higher interest rates in the periphery could be that they are necessary to compensate lenders for higher exchange rate volatility or credit risk, rather than higher liquidity risk. However, currency hierarchy is one plausible determinant of those variables, too (see section 2.3.1).

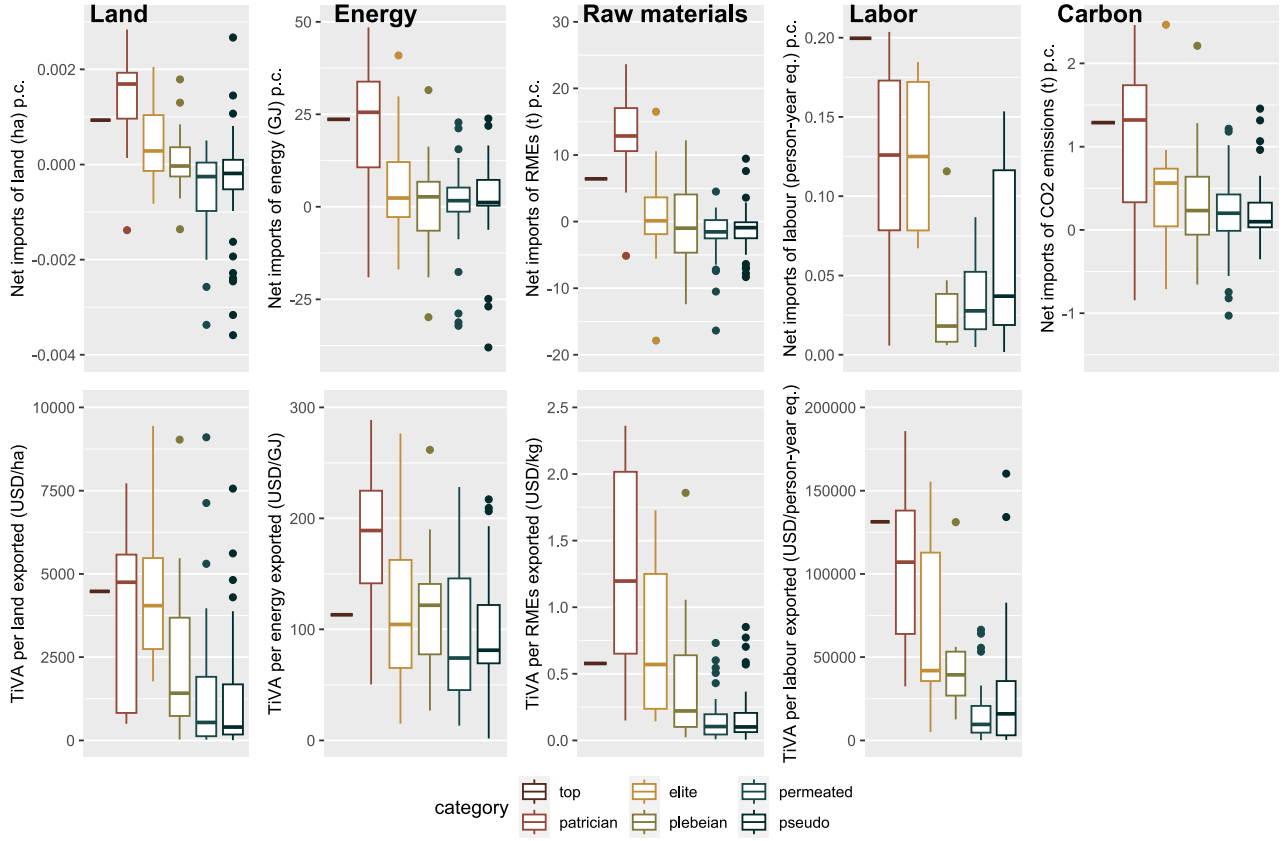

Figure 3. Correlations between currency categories and EUE.

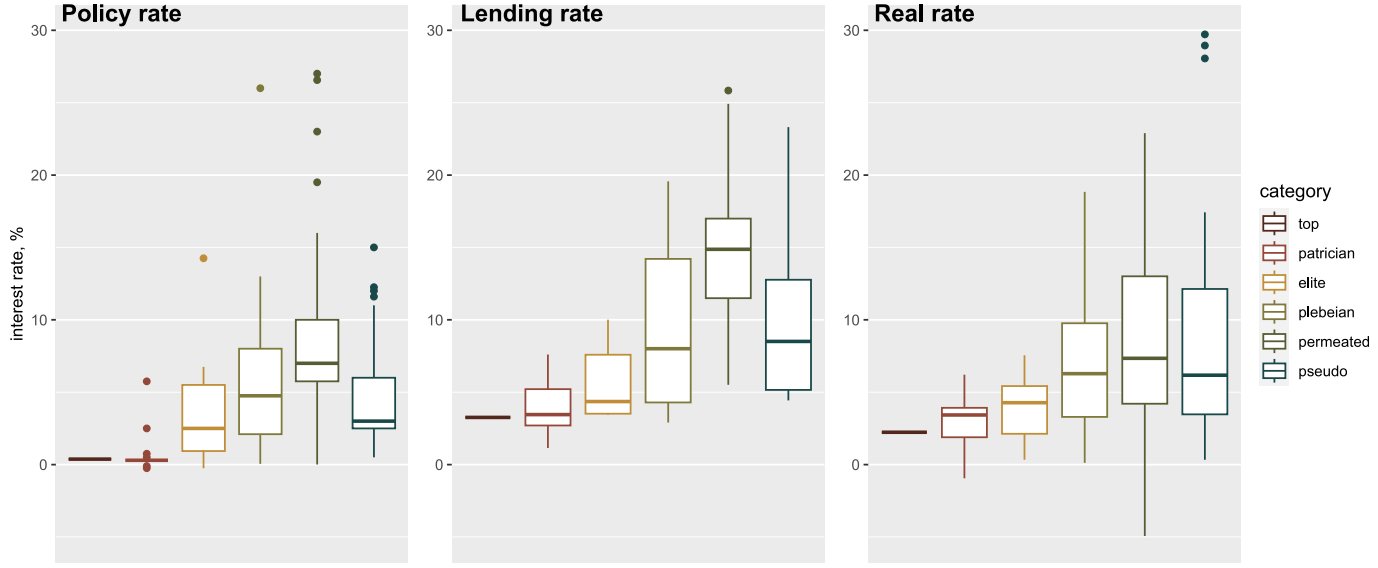

Fig. 4. Correlations between currency categories and interest rates.

More generally, by no means can the simple empirical tests presented here rule out all alternative explanations. However, given the extent of reasons to be skeptical about the BS and NIR hypotheses – the most salient orthodox explanations of the correlations at hand – the theoretical framework proposed in this paper deserves to be tested further. In particular, future research should establish the direction(s) and extent of causal effects between currency hierarchy and EUE, and control for alternative explanations.

Some additional empirical and conceptual limitations should be considered. Overall, the hypotheses can explain the empirical flows of labour, land, and raw materials relatively well. They are less powerful for energy and for carbon. It also remains an open question why countries with 'pseudo-currencies' tend to have lower interest rates and higher price levels than those with 'permeated' currencies. This observation clashes with existing theories of currency hierarchy and financial subordination (e.g. Cohen, 2015; Koddenbrock & Sylla, 2022).

On a more fundamental level, the entire concept of 'currency hierarchy' presumes that nation states are the relevant units of analysis, thus

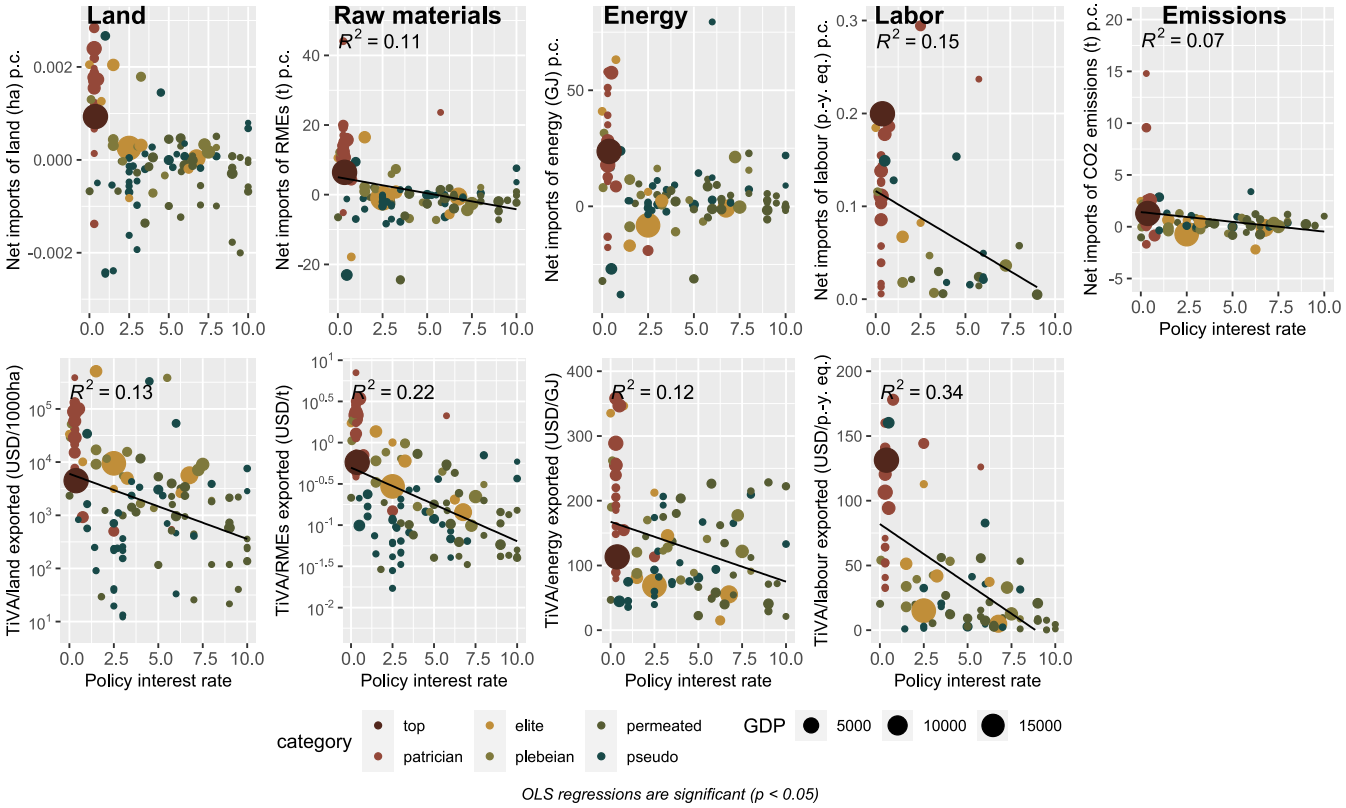

Fig. 5. Correlations between interest rates and ecologically unequal exchange.

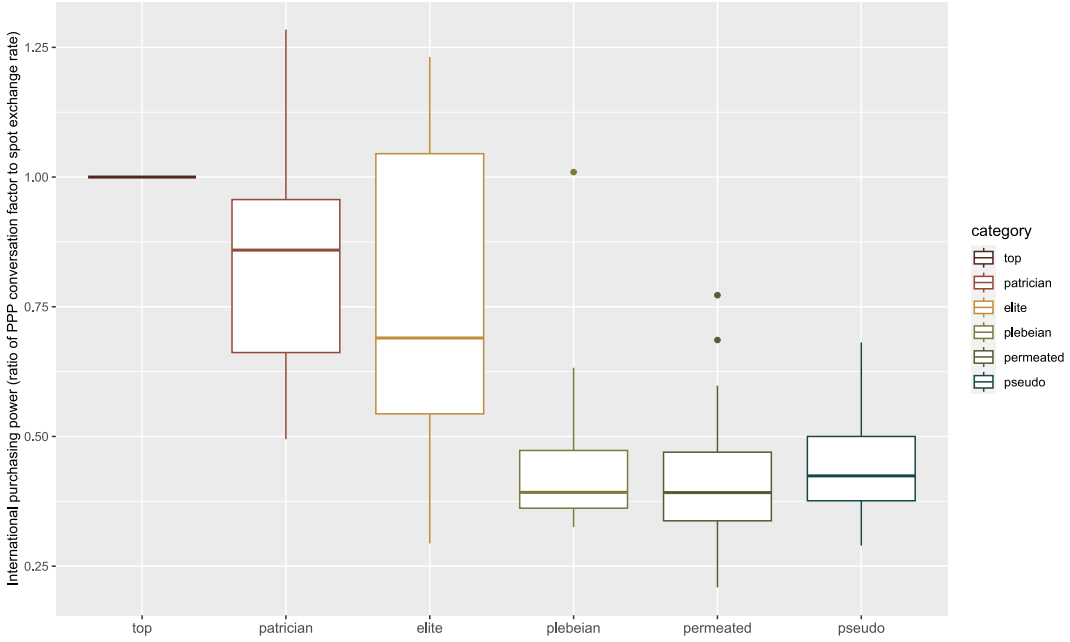

Figure 6. Correlation between currency categories and price levels.

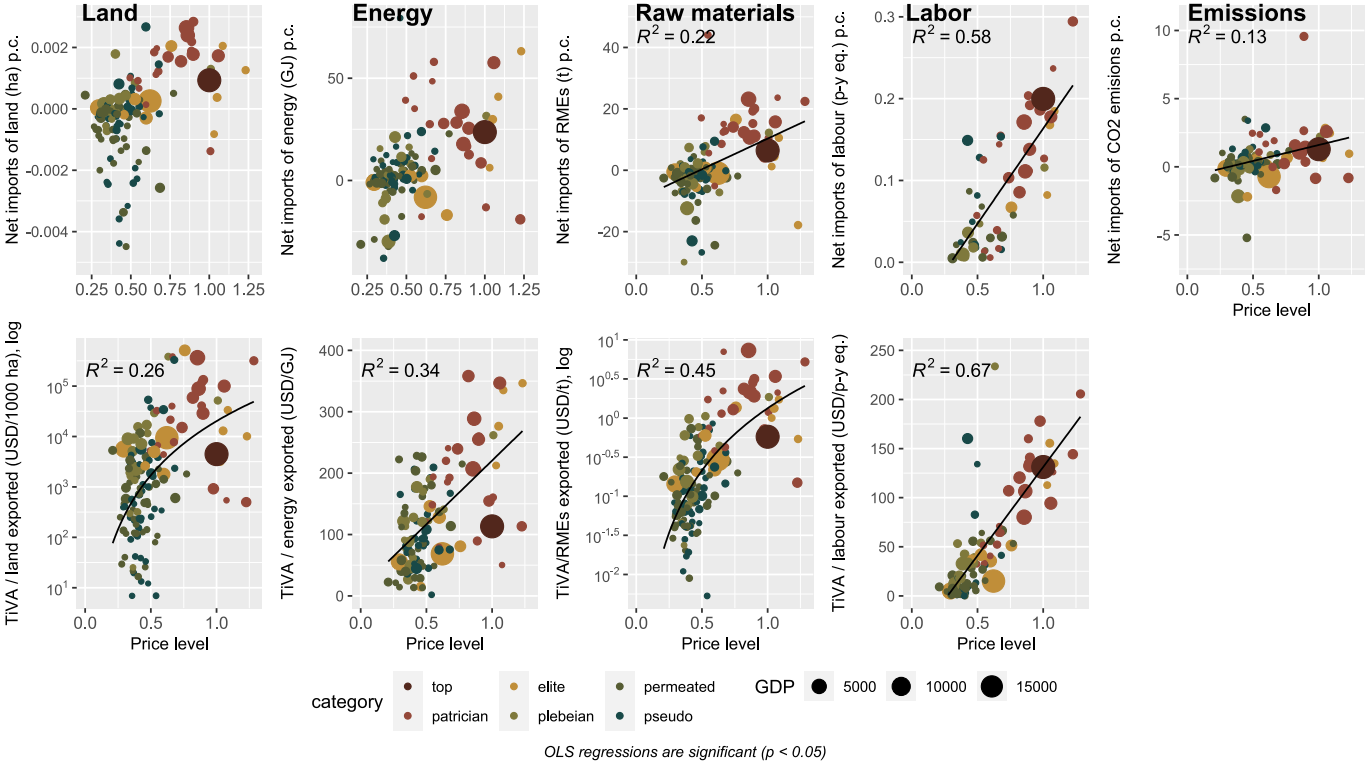

Figure 7. Correlations between price levels and ecologically unequal exchange.

Table 4
Multiple regression coefficients corresponding to hypotheses 4.1. and 4.2.

Model 4.1				
	Land	Raw materials	Labour	Energy
Intercept	5.6129***	− 3.21173***	8.25279***	4.11862 ***
Price level	4.5990***	3.73123***	3.94923***	1.30906 ***
Interest rate	−.1073**	−.05788***	−.07889**	.02778
Adjusted R^2	.3209	.5185	.4974	.2261
DF	128	129	94	108
Model 4.2				
	Land	*Raw Materials*	*Labour*	*Energy*
Intercept	6.283***	− 3.106***	8.393***	4.090***
Price level	.2513	3.067***	1.536**	1.595***
Interest rate	−.06858*	− 5.213**	−.04669	−.03087*
GNI p.c.	.00008095***	.00001230.	.00004.939***	.000005.640
Adjusted R^2	.4977	.5271	.6591	.2277
DF	127	128	93	107

Significance levels: *** p < 0.001, ** p < 0.01, * p < 0.05, p < 0.1.

abstracting from power relations within those units, and from offshore money creation (Binder, 2023). Future research should conceptually account for these forms of power.

4. Conclusion

This paper has developed and substantiated the argument that currency hierarchy has a significant effect on cross-border flows of embodied labour, land, energy, raw materials, and carbon emissions – that is, these flows are more asymmetric than they would be in a world without currency hierarchy. This effect is mediated by the impact of interest rates and price levels on the monetary valuation of resources embodied in exports: Countries with high-ranking currencies tend to have lower interest rates than peripheral countries, which increase their borrowing capacity, drive cross-border income flows in their favor, and favor specialization in less resource-intensive production. They also tend to have relatively higher price levels (i.e. high ratios of exchange rate to PPP rate), which make up part of the relatively higher monetary compensation that they receive for exported resources, and which lead to net resource inflows. These hypotheses, rooted in different strands of dependency theory, could not be rejected by some simple empirical tests. Alternative explanations of the empirical results do not appear much more plausible on both theoretical and empirical grounds. Therefore, it seems justified to conclude, for now, that currency hierarchy is among the drivers of ecologically unequal exchange. In biophysical terms, a dollar *costs* more in the periphery of the global monetary system than in its core. Consequently, countries with higher-ranking currencies can sustain net inflows of embodied energy, raw materials, land, labour, and carbon emissions from countries with lower-ranking currencies.

This conclusion, if it can be substantiated, has far-reaching political implications. It may remain difficult for peripheral countries to follow any autonomous and sustainable development trajectory unless there are structural reforms of the international monetary and financial system. Calls for monetary transfers from core to periphery feature prominently in current international climate policy debates, whether in the form of reparations (Táíwò, 2022), 'loss and damage' funds (Huq, Roberts, & Fenton, 2013), compensation for atmospheric appropriation (Fanning & Hickel, 2023), or the cancellation of peripheries' external sovereign debt (Nakate, 2022). However, to effectively reduce the asymmetric transfers of resources, such measures will have to be complemented by long-term structural changes that reduce the hierarchy between currencies (see also Sylla, 2023). One way to achieve this would be the introduction of an internationally acceptable currency under globally equitable governance, whether in the form of a global 'Carbon Coin' (Robinson, 2020), 'Ecor' (Aguila, Haufe, & Wullweber, 2022) or 'Green Special Drawing Rights' (e.g. UNCTAD, 2019; 2023). Of course, any steps towards a more equitable global monetary and economic system are predicated on the willingness and the ability of core countries to accept limits on their access to cheap imported resources

(see also Svartzman & Althouse, 2020). Effective measures to eliminate ecologically unequal exchange and its structural monetary drivers will be a key step towards stopping the collapse of the planet's climatic and ecological systems. Ultimately, that should be in the interest of both the core and the periphery. After all, they inhabit the same planet.

CRediT authorship contribution statement

Christopher Olk: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

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

Data availability

Data and R code will be made available upon request.

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Appendix

Table A1
Overview of all data .

Variable	Unit	n =	Source	For details see:
GNI p.c. (in constant 2015 PPP USD)	USD	155	WDI	https://data.worldbank.org/
Labour productivity	PPP-adj. USD/h	189	ILO	https://ilostat.ilo.org/topics/labour-productivity/
Price level ratio of PPP conversion factor (GDP) to market exchange rate	factor (US ≡ 1)	156	WDI	https://data.worldbank.org/
Policy interest rate	percent	148	IFS	IMF (2016)
Deposit interest rate	percent	116	WDI	https://data.worldbank.org/
Lending interest rate	percent	116	WDI	https://data.worldbank.org/
Real interest rate	percent	116	WDI	https://data.worldbank.org/
Share of foreign currency in external debt	percent	40	IFS	Kose et al., 2022
Net imports of embodied labour per capita	person-year equivalent	117	Eora26	Dorninger et al., 2021; Simas et al., 2015
Net imports of embodied land per capita	hectares	140	Eora26	Dorninger et al., 2021; Bruckner et al., 2015
Net imports of embodied energy per capita	gigajoule	160	Eora26	Dorninger et al., 2021; Owen et al., 2017
Net imports of embodied raw materials per capita	gigatons of Raw Material Equivalents (RMEs)	160	Eora26	Dorninger et al., 2021; Schaffartzik, Wiedenhofer, & Eisenmenger, 2015
Net imports of carbon emissions per capita	tons	113		Andrew & Peters, 2023
Trade in Value Added (TiVA) per exports of embodied labour	USD / person-year equivalent	117	Eora26	Dorninger et al., 2021; Simas et al., 2015
TiVA per exports of embodied land	USD / hectare	159	Eora26	Dorninger et al., 2021; Bruckner et al., 2015
TiVA per exports of embodied energy	USD / terajoule	128	Eora26	Dorninger et al., 2021; Owen et al., 2017
TiVA per exports of embodied raw materials	USD / gigatons of RMEs	160	Eora26	Dorninger et al., 2021; Schaffartzik et al., 2015

Sources and sample sizes

Table B1
Currency categories.

Country	ISO3C	Currency category
USA	USA	top
Australia	AUS	patrician
Austria	AUT	patrician
Belgium	BEL	patrician
Canada	CAN	patrician
Estonia	EST	patrician
Finland	FIN	patrician
France	FRA	patrician
Germany	DEU	patrician
Greece	GRC	patrician
Iceland	ISL	patrician
Ireland	IRL	patrician
Italy	ITA	patrician
Japan	JPN	patrician
Latvia	LVA	patrician
Lithuania	LTU	patrician
Malta	MLT	patrician
Netherlands	NLD	patrician
Poland	POL	plebeian
Portugal	PRT	patrician

(*continued on next page*)

Table B1 (*continued*)

Country	ISO3C	Currency category
Slovakia	SVK	patrician
Slovenia	SVN	patrician
Spain	ESP	patrician
Switzerland	CHE	patrician
UK	GBR	patrician
Brazil	BRA	elite
China	CHN	elite
Denmark	DNK	elite
India	IND	elite
Mexico	MEX	elite
New Zealand	NZL	elite
Norway	NOR	elite
South Africa	ZAF	elite
South Korea	KOR	elite
Sweden	SWE	elite
Algeria	DZA	plebeian
Croatia	HRV	plebeian
Czech Republic	CZE	plebeian
Georgia	GEO	plebeian
Ghana	GHA	plebeian
Hungary	HUN	plebeian
Indonesia	IDN	plebeian
Iran	IRN	plebeian
Israel	ISR	plebeian
Kenya	KEN	plebeian
Kuwait	KWT	plebeian
Malaysia	MYS	plebeian
Mongolia	MNG	plebeian
Romania	ROU	plebeian
Russia	RUS	plebeian
Thailand	THA	plebeian
Tunisia	TUN	plebeian
Turkey	TUR	plebeian
Afghanistan	AFG	permeated
Albania	ALB	permeated
Angola	AGO	permeated
Argentina	ARG	permeated
Armenia	ARM	permeated
Bosnia and Herzegovina	BIH	permeated
Botswana	BWA	permeated
Bulgaria	BGR	permeated
Burundi	BDI	permeated
Chile	CHL	permeated
Colombia	COL	permeated
Cuba	CUB	permeated
Dominican Republic	DOM	permeated
Egypt	EGY	permeated
Ethiopia	ETH	permeated
Gambia	GMB	permeated
Guatemala	GTM	permeated
Honduras	HND	permeated
Jamaica	JAM	permeated
Kazakhstan	KAZ	permeated
Kyrgyzstan	KGZ	permeated
Liberia	LBR	permeated
Madagascar	MDG	permeated
Malawi	MWI	permeated
Mauritania	MRT	permeated
Moldova	MDA	permeated
Mozambique	MOZ	permeated
Myanmar	MMR	permeated
Nicaragua	NIC	permeated
Pakistan	PAK	permeated
Paraguay	PRY	permeated
Peru	PER	permeated
Philippines	PHL	permeated
Rwanda	RWA	permeated
Serbia	SRB	permeated
Sierra Leone	SLE	permeated
Sri Lanka	LKA	permeated
Sudan	SUD	permeated
Suriname	SUR	permeated
Tajikistan	TJK	permeated
Tanzania	TZA	permeated
Turkmenistan	TKM	permeated
Ukraine	UKR	permeated

(*continued on next page*)

Table B1 (*continued*)

Country	ISO3C	Currency category
Uruguay	URY	permeated
Uzbekistan	UZB	permeated
Viet Nam	VNM	permeated
Zambia	ZMB	permeated
Azerbaijan	AZE	pseudo
Bahrain	BHR	pseudo
Bangladesh	BGD	pseudo
Belize	BLZ	pseudo
Benin	BEN	pseudo
Bhutan	BTN	pseudo
Bolivia	BOL	pseudo
Brunei	BRN	pseudo
Burkina Faso	BFA	pseudo
Cambodia	KHM	pseudo
Cameroon	CMR	pseudo
Cape Verde	CPV	pseudo
Central African Republic	CAF	pseudo
Chad	TCD	pseudo
Congo	COG	pseudo
Costa Rica	CRI	pseudo
Cote dIvoire	CIV	pseudo
Djibouti	DJI	pseudo
DR Congo	COD	pseudo
Ecuador	ECU	pseudo
El Salvador	SLV	pseudo
Eritrea	ERI	pseudo
Fiji	FJI	pseudo
Gabon	GAB	pseudo
Guinea	GIN	pseudo
Haiti	HTI	pseudo
Iraq	IRQ	pseudo
Jordan	JOR	pseudo
Laos	LAO	pseudo
Lebanon	LBN	pseudo
Lesotho	LSO	pseudo
Libya	LBY	pseudo
Mali	MLI	pseudo
Montenegro	MNE	pseudo
Morocco	MAR	pseudo
Namibia	NAM	pseudo
Nepal	NPL	pseudo
Niger	NER	pseudo
Nigeria	NGA	pseudo
Oman	OMN	pseudo
Panama	PAN	pseudo
Qatar	QAT	pseudo
Saudi Arabia	SAU	pseudo
Senegal	SEN	pseudo
Somalia	SOM	pseudo
South Sudan	SDS	pseudo
Swaziland	SWZ	pseudo
Syria	SYR	pseudo
TFYR Macedonia	MKD	pseudo
Togo	TGO	pseudo
Uganda	UGA	pseudo
Venezuela	VEN	pseudo
Yemen	YEM	pseudo
Zimbabwe	ZWE	pseudo

Table C1
Results for models M2 and M3 (used to draw regression lines in Figures 5 and 7).

M2 (Predictor: Policy interest rate)

Response	**Std.Estimate**	**Std.Error**	**DF**	**p**		**R^2**
Net imports of land p.c.	−0.1841	1e-04	132	0.0407	*	0.03
Net imports of raw materials p.c.	−0.2193	0.2325	132	0.0134	*	0.05
Net imports of labour p.c.	−0.5062	0.003	97	0	***	0.19
Net imports of energy p.c.	−0.139	0.6794	132	0.104		
Net imports of carbon p.c.	−0.2775	0.0461	100	0.0064	***	0.07
TiVA per land	−0.2281	1263.9201	131	0.011	*	0.05
TiVA per raw materials	−0.3723	0.0176	132	0	***	0.13
TiVA per labour	−0.3431	2030.6736	97	0.0029	**	0.09
TiVA per energy	−0.2051	2.7369	111	0.0482	*	0.03

(*continued on next page*)

Table C1 (*continued*)

M2 (Predictor: Policy interest rate)						
Response	**Std.Estimate**	**Std.Error**	**DF**	**p**		**R^2**
M2 (Predictor: Lending interest rate)						
Net imports of land p.c.	−0.1119	8e-04	95	0.35		
Net imports of raw materials p.c.	−0.0342	1.9281	95	0.7064		
Net imports of labour p.c.	−0.4264	0.0178	69	0	***	0.3
Net imports of energy p.c.	−0.0364	5.4088	95	0.667		
Net imports of carbon p.c.	−0.1234	0.3333	70	0.1741		
TiVA per land	−0.4708	11657.4986	94	0	***	0.19
TiVA per raw materials	−0.418	0.1245	95	0	***	0.25
TiVA per labour	−0.4367	16979.3988	69	4e-04	***	0.17
TiVA per energy	−0.1901	26.5267	78	0.1302		
M3 (Predictor: Price level ratio of purchasing power parity rate to spot exchange rate)						
Response	**Std.Estimate**	**Std.Error**	**DF**	**p**		**R^2**
Net imports of land p.c.	−0.0023	0.0017	140	0.9788		
Net imports of raw materials p.c.	0.2606	5.2924	140	0.002	**	0.07
Net imports of labour p.c.	0.6078	0.047	99	0	***	0.44
Net imports of energy p.c.	0.1831	16.1915	140	0.0312	*	0.03
Net imports of carbon emissions p.c.	0.33	0.95	105	2e-04	***	0.12
TiVA per land	0.3732	27356.3106	139	0	***	0.14
TiVA per raw materials	0.6166	0.3402	140	0	***	0.37
TiVA per labour	0.4762	33992.3673	99	0	***	0.27
TiVA per energy	0.3352	53.4617	116	1e-04	***	0.12

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