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Abstract:	The concept of ecological unequal exchange (EUE) is the methodological basis for proving that the global North is ecologically exploiting the global South. Technological progress in the North leads to ever greater exploitation of nature in the South. Numerous studies now exist on this subject. It is striking that the theoretical basis of the EUE approach is often merely a reference to the analogy of the unequal exchange of labor values according to Emmanuel. Proponents of this approach see the "ecological balance of payments" as an indicator of ecological exploitation and unfair trade. This paper shows that no reliable indicator of exploitation can be derived from the virtual or actual resource flows between the South and the North that underlie commodity flows. For this purpose, a generalized Ricardo model of foreign trade is employed, and it is first shown that there is no systematic relationship between physical resource flows and the welfare distribution of trade. The concept of a balanced net physical flow of resources between North and South is not only unsuitable for diagnosing whether exploitation is occuring, but also leads to potentially misguided policies in North-South relations, e.g. it increases the likelihood of international resource conflicts.

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Unveiling ecological unequal exchange: The role of bio-physical flows as an indicator of ecological exploitation in the North-South relations

by
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The concept of ecological unequal exchange (EUE) is the methodological basis for proving that the global North is ecologically exploiting the global South. Technological progress in the North leads to ever greater exploitation of nature in the South. Numerous mostly empirical studies now exist on this subject. It is striking that the theoretical basis of the EUE approach is often merely a reference to the analogy of the unequal exchange of labor values according to Emmanuel. According to Emmanuel, there is international exploitation of labor if the labor values of production are not exchanged 1:1 between countries or groups of countries. The same applies in the EUE to unequal ecological exchange. However, the focus here is not on the value of labor, but on the consumption of resources and nature (sinks, landfills, etc.). Proponents of this approach see the "ecological balance of payments" (Roepke) as an indicator of the existence and extent of ecological exploitation and unfair trade. This paper shows that no reliable indicator of exploitation can be derived from the virtual or actual resource flows between the South and the North that underlie commodity flows. For this purpose, a generalized Ricardo model of foreign trade (the so-called Dornbusch-Fischer-Samuelson model) is employed, and it is first shown that there is no systematic relationship between physical resource flows and the welfare distribution of trade. The concept of a balanced net physical flow of resources between North and South is not only unsuitable for diagnosing whether exploitation is occuring, but also leads to potentially misguided policies in North-South relations, e.g. it increases the likelihood of international resource conflicts. This result is confirmed by another corollary, which shows that transfers from the North to the South do not necessarily lead to an improvement in the net material position of the South. Although the transfer is welfare enhancing, it is not reflected in the physical flows. We also find that the claim that inequality of ecological exchange increases with technological progress in the North depends on the direction of technological progress.

JEL codes: F11 (Necoclassical Models of Trade), Q27 (Issues in International Trade), Q56 (Environment and Trade), Q57 (Ecological Economics)

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1 Introduction

Since the 1980s, the paradigm of the injustice of international trade in natural resources and environmental damage has shaped the critical political perception of the globalization and international trade policy. "*More trade, more environmental destruction*" has become the catch phrase of the anti-globalization movement ever since the massive public protests at the World Trade Organization meeting in Seattle in 1999. Even today, more than 20 years later, the topic of ecologically unequal exchange is still on the agenda. Images of large-scale deforestation in the countries of the global South in favor of environmentally damaging monocultures such as oil palms and soybeans are continually appearing in the media. But does an unequal bio-physical exchange of goods and services prove that the developed North is ecologically exploiting the developing South? Is the growing prosperity and technological progress in the North leading to an ever-increasing exploitation of nature in the South? In this paper, we demonstrate that there is no systematic relationship between physical resource flows and the distribution of trade gains. Furthermore, we show that the concept of a balanced net physical flow of resources between North and South is not only inappropriate to diagnose whether exploitation is occurring, but also leads to potentially misguided policies in North-South relations that, for example, could increase the likelihood of international resource conflicts. The structure of this paper is as follows. In Section (2), we provide a basic overview of the theories of unequal exchange and ecological exploitation in the literature. In Section (3), we rigorously prove in a generalized Ricardo model of foreign trade that there is no systematic relationship between physical resource flows and the distribution of trade gains. We also refute the claim that inequality of ecological exchange generally increases with technological progress in the North. And we show that transfers from the North to the South do not necessarily lead to an improvement in the net material position of the South. Section (4) shows how the mismeasurement of EUE leads to misguided resource policies, including increasing the possibility of international resource conflicts.

2 Ecologically unequal exchange (EUE) and theories of exploitation in the literature

The understanding of exploitation through unfair exchange encompasses various historical and theoretical perspectives that have evolved over time. Originally, exploitation was considered in the context of commodity exchange, where one party gained an unfair advantage at the expense of the other party, such as through inflated prices or inferior goods trade. This concept was explored by philosophers like John Locke before being further developed by Karl Marx.

Marx coined the term exploitation in connection with the labor theory of value, which posits that exploitation occurs in the sphere of production, where workers receive wages lower than the value of their labor, creating the famous „surplus value“ that according to marxist’s theory becomes the „motor force“ of profit-driven capitalistic development. Marx’s ideas was later extended to international trade by other

Marxist thinkers like Arghiri Emmanuel, who measured unfair commodity exchange between nations based on the theory of labor value. "Unequal exchange" in Emmanuel's theory implies that on the world market the poor, peripherical countries of the global South are forced to sell their products with a relatively large quantum of labor embedded in order to obtain in exchange commodities embodying a much smaller quantum of labor from the rich countries of the world. As a result „surplus labor" accumulates and drives the further development in the core countries of the global North.[1] Dependency theory, as for example advocated by Frank (1967), described this process as a historical „development of underdevelopment" in countries of the global South, with or without explicitly referencing Emmanuel's labor theory of international relations.

This structuralist view of the asymmetry between South and North was already developed before the Marxist analysis by Prebisch and Singer. The latter introduced the distinction between the South and the North. The structural asymmetry is primarily caused by the different labor markets, in the South with its infinitely elastic labor supply at a subsistence wage, and the North with a labor market with an institutionally controlled labor supply. Depending on the elasticities of import demand in the South and North, technological progress can lead to a deterioration in the terms of trade in the South and, thus, to an impoverishment of workers in the South (Prebisch-Singer thesis[2]).

The theory of exploitation based on the labour theory of value was only ever developed in the context of the capitalist economic system.[3] Roemer (1982), on the other hand, developed a general theory of exploitation that can be applied to different economic systems and that utilizes the game-theoretical concept of withdrawal from contracts. He develops and generalizes the concept of exploitation decisively further by not defining exploitation in terms of an exchange relationship of, say, embodied labor but in terms of a benchmark of a fair distribution of resources; in the context of Marx's approach, the distribution of capital.[4] Roemer thus places the problem of exploitation in the more general context of a theory of justice.[5] One consequence of this approach is that questions of justice in international trade can also be analyzed in the context of neoclassical foreign trade models, for example, by examining the welfare effects of the trade from the perspective of the game theory core and cooperative bargaining theory (see Section (3.4)). This approach relies on the given feasibility of a better alternative to make individuals or members of a group better off by withdrawing from any present allocation system to a feasible hypothetical alternative. This can be applied to the class of workers *in a country*

[1]Emmanuel argues that the structure and functioning of the capitalist world market is determined by a definite law of price formation which involves in „an unequal rewarding of factors," most notably, the „labor factor". This law tends to produce an „inequality in exchange" between rich and poor countries. This inequality, Emmanuel argues, in turn dictates an international division of labor which is detrimental to the interests of the latter group of countries. See Emmanuel (1972) and the overview in Hickel et al. (2022).

[2]See the nutshell model comparing the analysis of Prebisch and Emmanuel by Bacha (1978).

[3]See for a concise analysis Morishima (1974).

[4]See Roemer (1982), chapt. 7, and a further elaboration by Fleurbaey (2014).

[5]See Roemer (1996).

or to a country of the global South in *international negotiations*. Roemer' s theory encompasses both of those Marxists theories of unequal exchange.

The ecological perspective of unequal exchange between core countries and peripheral countries or regions emerged in the 1980s in the wake of a groundbreaking study of Bunker (1988) on the emergence of a specific "mode of extraction" in the Brazilian Amazon regions, which led to an unequal distribution of extraction costs and benefits that favored importing regions in the global North. The subsequent contributions, which have been carefully compiled in an anthology by Frey et al. (2018), are based on various theoretical perspectives, from Marxist and world systems approaches (following Wallerstein (1974), and Amin (1972)) to thermodynamics (Georgescu-Roegen (1971)) and Odum's energy value theory (Odum (1971)). It is interesting to note that many studies have used detailed regionalised input-output models and carried out extensive data analyses. The theoretical basis of this approach is often only a reference to the analogy of unequal exchange of labor values as developed by Emmanuel. Overall, the understanding of exploitation through unfair exchange is a complex subject that encompasses various theoretical perspectives and historical developments, which continue to be researched and debated.[6]

In this paper, we operate beyond the realm of Marxist theories of exploitation based on labor value theories. We examine instead the biophysical/material components of value in commodity exchange following the ecological perspectives of unequal exchange. Our aim is to reveal the inconsistencies of this approach with Roemer's approach of a generalized theory of exploitation and demonstrate the counterintuitive impacts of this „measurement failure“ on widely accepted policies to overcome the „North-South divide“ through greater participation in technological advancements and international transfer policies.

Importantly. we do not analyze the exploitation of nature per se (e.g., deforestation or overfishing) but the biophysically measured exploitation by means of unequal exchange in international relations (following world system theories). Please note that this is done in full congruence with the ecological perspective on unequal trade that also only looks into the unequal distribution of the benefits of resource extraction in favor of importing nations of the global North (Hornborg (2012)).

It remains to be mentioned, there are approaches that link the „overexploitation“ of natural resources with the volume of international trade. e.g. Chichilnisky (1993) and Brander and Taylor (1997). These are constructed without reference to material flows. They are driven by a lack of property rights („open access“) in the exploitation of these resources or weak judicial and labor market institutions[7] in a ruinous supplier competition of the countries of the global south. This additional institutional deficiency is not taken into account in our paper as we focus on the simple North-South relationships in the sense of EUE and world systems theories.

[6] There are now a large number of studies that use advanced input-output accounting methods to calculate the resource flows on which international trade is based. See for example Dorninger et al. (2021) and Lenzen et al. (2013). A typology of EUE is developed in Andersson and Lindroth (2001).

[7] Shapiro (2023) emphasises the importance of a strong institutional framework for the environmental cleanliness of industries in an empirical study. See also the overview of Fischer (2010).

There is a close connection between the theories of ecological exploitation and the theories of virtual water trade. Virtual water is the water embboddied in products, not in a bio-physical sense, but in virtual sense. It refers to the water needed for the production of the products (Hung (2002)). Virtual water content is nothing else as a life cycle accounting of water similar to energy balance approaches etc. The claim made by virtual water theory is that trade increases a globally uneven water distribution. High water scarcity, as for example in the Middle Eastern Countries, makes it attractive to import virtual water and thus make those countries become even more water dependent. „The mechanisms of international trade in staple foods continue to operate with proven effectiveness to ameliorate the uneven water endowments on the world's regions", states Allan (1998), a pioneer in virtual water trade research. At the same time virtual water trade reduces the potential of water conflict. Virtual water trade prevents water scarcity becoming the cause of water wars, e.g. in the Middle East (Allan (2002) and Allan (2003)). From this point of view virtual water trade should even be encouraged in drafting water policy plans.

Aside from the weak empirical evidence supporting these claims (see Kumar and Singh (2005)), the impacts of virtual water trade on resource fairness have been subject to critical scrutiny. The "leveling" of virtual water in global trade – in keeping with the EUE narrative and the fight against ecological exploitation – not only fails against the backdrop of neoclassical trade theory ("mutual gains"), but turns out to be completely demonstrably out of context with comparative advantages (Ansink (2010) and Reimer (2012)). The same or similar rejections can be expected from related virtual resource theories such as the "land grabbing" theories (Magdoff (2013)). This led us to assume an abstract EUE framework for trade in a single natural resource in this paper.

3 Ecologically unequal exchange in an extended Ricardian trade model

3.1 Equality of resource flows versus equality of welfare

The relationship between biophysical flows and trade flows can be well analyzed within the extended Ricardo trade model[8] developed by Dornbusch et al. (1977).[9] The production of goods in both the South and the North is based on using only one input, namely a resource or an aggregate of resources. There is a continuum of goods indexed z on an interval $[0, 1]$. Required resources per output of z are $a_J(z)$, where $J = \{S, N\}$ where S is South and $N =$ North, i.e. $a_J(z)$ are constant

[8]Ricardo's one-factor model is suitable for reconstructing the bio-physical approaches in pure foreign trade theory. Since the EUE approaches do not deal with the functional distribution within countries, an analysis within the framework of multi-factor models (Heckscher-Ohlin models) can be dispensed with here. See Felbermayr et al. (2017) for the significance of the Ricardo model for analyzing the global trade system.

[9]An explanation of the model can also be found in the textbook of Gandolfo (2013). As this is a standard model of advanced foreign trade theory, the details, are transferred to the appendix (Section (6)). Technical details with respect to links between the commodity trade and biophysical flows are also relegated to the appendix.

input-output coefficients with regard to the produced quantity of the good z. The comparative advantage of producing z in the South compared to the North is $A(z) = a_N(z)/a_S(z), z \in [0,1]$. The index z is ordered such that $A(z)$ decreases in z, i.e. the comparative advantage of the South decreases in z. Therefore, $A'(z) < 0$.

International production specialization depends on the prices of goods. Under the (usual) assumption of the basic Ricardian model, there is perfect competition, so the product supply prices follow from the following price equations.

$$p_J(z) = a_J(z)q_J, \quad J = \{S, N\} \tag{3.1}$$

where q_J refer to the resource price of the South and the North, respectively. The South will produce those goods with a lower price compared to the North, i.e.

$$a_S(z)q_S \leq a_N(z)q_N \tag{3.2}$$

From Equation (3.2) it follows

$$\omega := q_S/q_N \leq a_N(z)/a_S(z) = A(z) \tag{3.3}$$

where ω is the factoral terms of trade[10] which indicates the exchange ratio of the resources embodied in the goods traded. Subsequently, we show that this exchange ratio is the decisive indicator for determining ecologically unequal exchange.[11]

From Equation (3.3) we can find the borderline commodity

$$\bar{z} = A^{-1}(\omega) \tag{3.4}$$

which divides the product space into goods $z \leq \bar{z}$ with the South having a comparative advantage and goods $z > \bar{z}$ where the North produces comparatively cheaper.

The demand for the commodities are derived from a Cobb-Douglas utility function for both, the South and the North, assuming identical preferences.[12] This task is simple also for the case of a continuous spectrum of goods.[13] The demand functions are:

$$c_J(z) = \frac{b(z)Y_J}{p(z)}, \quad J = \{S, N\} \tag{3.5}$$

where Y_J is the income and $p(z)$ the market price for z. Under free trade without transportation costs, a uniform price $p(z)$ applies for z. Depending on which country group offers product z, the offer price $p_J(z)$ is equal to the market price $p(z)$. Hence, due to the decreasing comparative advantage of the South, i.e. $A'(z) < 0$, there exists a $\tilde{z}, 0 < \tilde{z} < 1$, such that South produces all commodities z within the interval $[0, \tilde{z}]$

[10] For a definition and discussion of various concepts of the terms of trade, see Findlay (1991).

[11] In Section (6.2) it is shown that the factoral terms of trade measure the (virtual) bio-physical flow of resources between the South and the North.

[12] This restrictive assumption allows a simple graphical representation of the relationships below. Since we only want to use an example to illustrate the ambiguity of the relationship between biophysical flows and trade equality, this simplification is justified. For an extensions of the model, see Wilson (1980).

[13] The derivation can be found in Section (6.1).

whereas the North produces the remaining products $z \in [\tilde{z}, 1]$. Resource market equilibria are achieved if total demand equals the supply, i.e.

$$\int_0^{\bar{z}} a_S(z)[c_S(z) + c_N(z)]dz = \bar{R}_S \tag{3.6}$$

$$\int_{\bar{z}}^1 a_N(z)[c_S(z) + c_N(z)]dz = \bar{R}_N \tag{3.7}$$

where $\bar{z}$ indicates the equilibrium value of $\tilde{z}$ and where $a_J(z), J = \{S, N\}$ are the input-output-coefficients. From Equation (3.1) it follows for $z \in [0, \tilde{z}]$ that $p(z) = p_S(z) = a_S(z)q_S$, i.e. the prices of the commodities produced by the South depend on the respective input-output coefficients and the price for the resource $\bar{R}_S$. Similar, the prices for the products produced in the North $z \in [[\tilde{z}, 1]$ are $p(z) = p_N(z) = a_N(z)q_N$. Inserting these relations and Equation (3.5) into Equation (3.6) yields:

$$\int_0^{\bar{z}} \left[b(z)\frac{Y_S}{q_S} + b(z)\frac{Y_N}{q_S} \right] dz = \bar{R}_S \tag{3.8}$$

Income in the South and North is generated in the factor market. Therefore, $Y_J = q_J\bar{R}_J$ applies where $\bar{R}_J$ symbolizes the fixed supply of resources in both country groups. This supply is exogenously given, and in this pure trading model, it is open whether it is sustainable or associated with an over-exploitation of resources.

Define

$$\theta(\bar{z}) = \int_0^{\bar{z}} b(z)dz \tag{3.9}$$

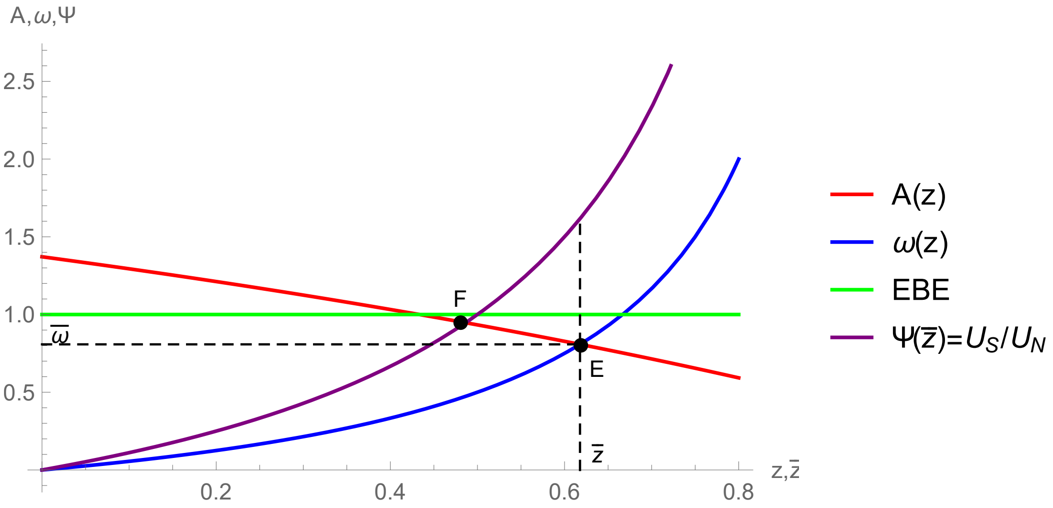
and utilizing $\omega = q_S/q_N$ together with $Y_J = q_J\bar{R}_J$ yields after insertion into Equation (3.6)

$$\theta(\bar{z})\omega\bar{R}_S + \theta(\bar{z})\bar{R}_N = \omega\bar{R}_S \;\Rightarrow\; \bar{\omega} := \omega(\bar{z}) = \frac{\theta(\bar{z})}{1 - \theta(\bar{z})}(\bar{R}_N/\bar{R}_S) \tag{3.10}$$

Equation (3.10) shows the factoral terms of trade as function of the relative endowment of resources and as a function of the range of products the South is producing in trade equilibrium, i.e. $\bar{z}$. The bandwith of the range depend on the comparative advantages as defined in Equation (3.4). In the following figure we depict both functions, $A(z)$ and $\omega(z)$ and determine graphically[14] the equilibrium value of $\bar{z}$ along the x-axis (point E).

The range of commodities $z \in [0, \bar{z}]$ are produced by the South, all $z \in [\bar{z}, 1]$ are produced by the North. The trade equilibrium adjusts the input prices q_J such that the factoral terms of trade are $\bar{\omega} = \omega(\bar{z})$ defined in Equation (3.10). The welfare distribution between the South and the North is expressed as $\Psi(\bar{z}) = U_S(\bar{z})/U_N(\bar{z})$ and depends on the trade equilibrium $\bar{z}$. $\Psi(\bar{z})$ is a positively monotone function with respect to $\bar{z}$ indicating that the welfare of the South rises disproportionally high as the range of commodities produced in the South increases. The horizontal line marks the case of ecologically balanced exchange (EBE), i.e. the case were

[14] The equilibrium can also be determined algebraically by solving Equation (3.4) and Equation (3.10).



Source: Own illustration.

Figure 3.1: factoral terms of trade and the production range of the South

the net flow of resources of the South to the North are zero. In our our numerical example[15], trade equilibrium leads to ecologically unequal exchange between since the factoral terms of trade are less than unity.

Result 1 *The net outflow of resources from the South to the North cannot be used as an indicator of the ecological exploitation of the South.*

The result follows from the fact that trading in the Ricardo model is voluntary. Exploitation can only exist if trade is forced because the state of autarky would make the South better off. In our numerical example, on which the figure is based, gains of trade are realized for both, the South and the North, even though the factoral terms of trade are to the South's disadvantage.[16] If $\omega < 1$ there is a net flow of biophysical matter from the South to the North. The level of net biophysical flows, therefore, does not indicate ecological exploitation. This would only be the case if the South were to give up the possibility of realizing trade advantages in the future due to an excessive outflow of resources today. Thus, the level of factoral terms of trade $\omega < 1$ cannot per se be used to infer the exploitation of resources in the South. To infer exploitation requires further independent information relating to the sustainability of the resource consumption of $\bar{R}_S$ and $\bar{R}_N$.

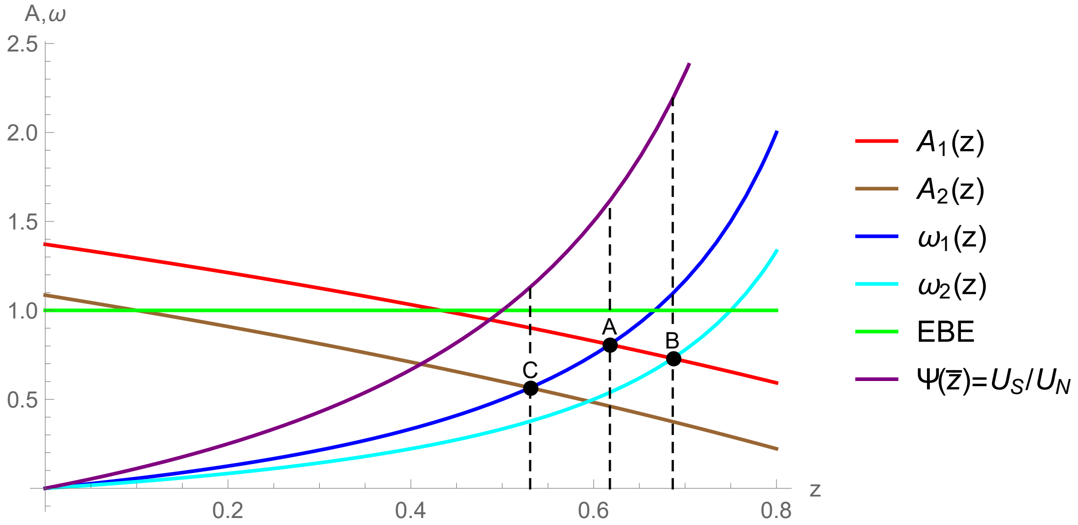
Result 2 *The net outflow of resources from the South to the North cannot be taken as an indicator of unfair trade.*

The fairness of the welfare distribution is shown in Figure (3.1) by the $\Psi-$function. The more comprehensive the range of goods produced in the South is, i.e. the higher

[15]The Figure is based on the following parameters and numerical values: $a_N = 4.8 - 4z$, $a_S = 3.5 - z$, $b(z) = b = 1$. Hence $\omega(z) = [z/(1-z)](R_N/R_S)$ with $R_N = 100$ and $R_S = 200$. From Equation (6.10) it follows that $\Psi(\bar{z}) = \bar{z}/(1-\bar{z})$.

[16]See Findlay (1982) and Roemer (1983).

$\bar{z}$ is, the greater the welfare of the South compared to the North. Figure (3.2) shows two scenarios that illustrate the non-monotonicity of the relationship between the factoral terms of trade and welfare distribution.



Source: Own illustration.

Figure 3.2: factoral terms of trade and welfare distribution

In the first case, the factor input of the South increases such that the trade equilibrium shifts from A to B implying that the factoral terms of trade have fallen to the disadvantage of the South. At the same time, however, the welfare distribution improves in favor of the South since $\bar{z}$ has increased. Thus, increased resource consumption, provided it is ecologically sustainable, is beneficial overall for the South, although the factoral terms of trade are falling. Welfare of the South rises not only in absolute terms but also in relative terms. This means that a deterioration in the factoral terms of trade leads to an improvement in the distribution of welfare in favor of the South. In the second scenario beginning at point A, all-encompassing technological progress in the North causes a reduction in the input-output coefficients of the North so that the $A(z)$ curve shifts downwards. In this case, a new equilibrium is established with lower factoral terms of trade for the South (point C). At the same time, the distribution worsens to the disadvantage of the South. The decline in the terms of trade is associated with a deterioration in the distribution of welfare. The reason for this is the advancement of technologies in the North, a relationship that not only representatives of the EUE have pointed out[17] but also other economists[18] referring to the heading of a 'technology gap'.

The two cases show that there is no clear monotonic relationship between biophysical flows and the distribution of trade gains between the two blocks of countries. Whether there is a positive or negative correlation between the welfare distribution and the factoral terms of trade depends on the exogenous determinants that influence the relative resource flows expressed by ω and the welfare distribution. Whether

[17] See e.g. Althouse et al. (2023).

[18] See a brief overview in Cimoli (1988).

there is a positive or negative correlation between the welfare distribution and the factoral terms of trade depends on the exogenous determinants that influence $\bar{\omega}$ and Ψ.

3.2 Technological gaps and asymmetric technological progress

According to the EUE approach, asymmetric technological progress, i.e., the faster technological development of the North, leads to an increasing exploitation of resources in the South because technological progress displaces the production of the South into resource extraction (see e.g. Althouse et al. (2023)). This relationship is illustrated in Figure (3.2) for the scenario 2 (the shift in equilibrium from A to C). Although the welfare of both hemispheres increases in the course of technical progress in the North the distribution changes to the disadvantage of the South. As the technological progress of the North increases, the $A(z)$-curve shifts downwards because the input-output coefficients of the North decrease.[19] As a result, the relative position of the South in terms of welfare distribution decreases. This argument assumes that technical progress relates to the production of all goods, including those that the North does not produce.

However, technical progress will relate more to those production processes that are used in both hemispheres, i.e., technical progress will be directed towards the respective domestic production. There is a similarity here with the concept of neutral technical progress in growth theory (Hicks neutrality). This approach has been criticised by Atkinson and Stiglitz (1969), who argue that technical progress depends on factor proportions.[20] Instead, they have developed the concept of *"localized technical progress"*, which in our context means that technical progress has only an impact on the actual production processes.

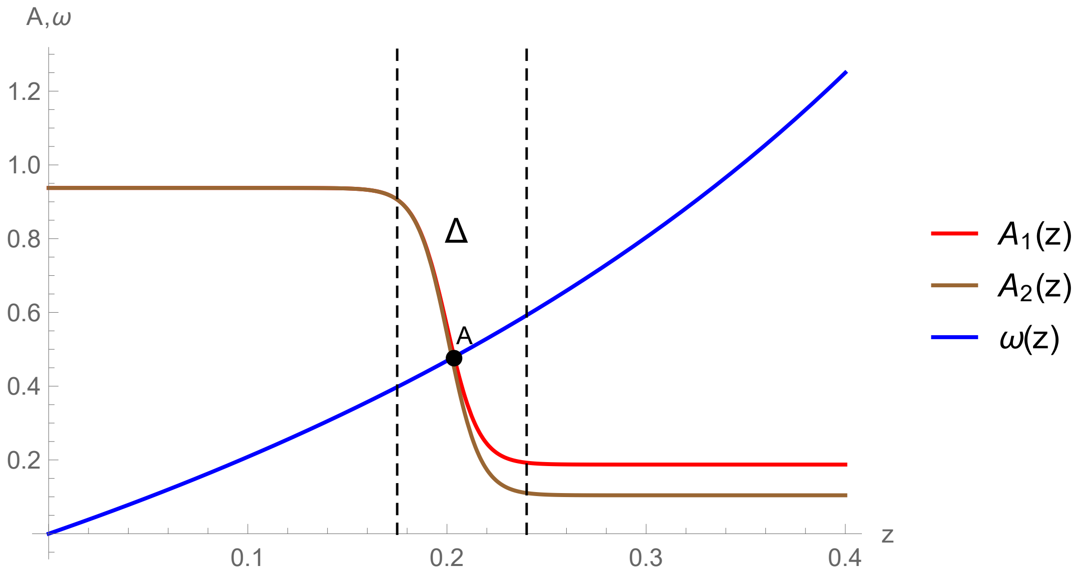
The localized technical concept can also explain why the North's one-sided, continuous innovation process leads to a technological gap. The $A(z)$-curve falls steeply after a critical threshold value[21] because the input-output coefficients of the North only decrease after this threshold value. This leads to an entrenchment in the global production division: the South tends to produce technologically simple goods, while the North produces high-tech goods. This technology gap can be expressed as a smooth approximation of a step in the $A(z)$-curve (see Figure (3.3)).

The curve drops steeply in the Δ-range of z. To the right of the Δ-range, the comparative cost advantages of the North are considerable. This does not apply to the left-side. Technologically simple products can be produced more cheaply in the South than in the North with the help of low labor costs. The figure now analyzes how technological progress in the North affects the terms of trade and the welfare distribution. We assume that technological progress does not relate to the production of goods manufactured in the South. This assumption is based on the fact that technological progress tends to take place in the area of actual production

[19]Recall the definition $A(z) = a_N(z)/a_S(z), z \in [0, 1]$.

[20]See also the discussion and further development of Acemoglu (2015).

[21]Cimoli (1988) has introduced an elasticity of technological gap that measures the steepness of the technological divide.



Source: Own illustration.

Figure 3.3: Technological progress in the North

processes. Technological progress in the North is now characterized by the $A(z)$-curve shifting asymmetrically from $A_1(z)$ to $A_2(z)$ leading to the result:

Result 3 *Technological progress in the North does not necessarily lead to a deterioration in the factoral terms of trade and the distribution of welfare between the South and the North. In addition, welfare has risen in both hemispheres.*

Thus, technological progress in the North is not necessarily at the expense of the South as claimed in the EUE-literature. Although the terms of trade are falling to the disandvantage of the South, the distribution of welfare is not changing. Here, the technological divide even provides protection against a shift in value creation from the South to the North ($\bar{z}$ remains stationary). However, if technological progress takes place in such a way that the North can also produce the goods of the South more cheaply, this can lead to a deterioration in the terms of trade and and an associated negative shift in welfare distribution for the South. Still, both hemispheres benefit from technological progress, albeit to varying degrees.

3.3 A neo-Ricardian reconstruction of EUE within the DFS-model

In contrast to the standard two-factor neoclassical foreign trade models, which include the DFS model, in neo-Marxist theory, the distribution of income between labor and capital is not determined according to the scarcity and productivity of the two factors but is the result of political-economic power relations, which Emmanuel refers to as 'extra-economic factors'[22]. The exchange relations of interna-

[22]See Emmanuel (1972) e.g. p. 116. He describes the formation of wages as inherently "institutional".

tionally traded goods between the periphery and the centre (barter terms of trade) then follow from the predetermined wage-profit-rate ratio. The unequal exchange about the exchange of labor values is, therefore, the result of these power relations, which do not result from the relative factor endowments as derived, e.g.,in the H-O-model. The neoclassical interpretation of the Ricardian one-factor model of international trade is also rejected. There, the international exchange relationships are determined by different production techniques and the relative factor endowments between the trading partners. Analytically, the neo-Marxist approach is expressed using the Marxian value and price determination scheme. However, using the Marxian scheme leads to problems with consistent separation between labor values and market prices. In a later contribution[23], Emmanuel therefore also transferred his theory of unequal exchange into a neo-Ricardian framework.[24].

His basic conclusion is[25]

> *that the inequality of wages as such, all other things being equal, is alone the cause of the inequality of exchange.*

where wage levels are not the result of supply and demand in a free labor market, but are formed in a political-economic process, i.e., are model-exogenous. If we transfer this labor value theory approach to the resource exchange relationship between the South and the North, we can represent this approach by the following modifications of the price Equation (3.1) of the DFS-model:

$$p_J(z) = a_J(z)\bar{q}_J(1+r), \quad J = \{S, N\} \tag{3.11}$$

where the bars indicate that resource prices are fixed and r is the global rate of return on capital. An essential element of the global economy for Emmanuel is the unrestricted mobility of capital. Therefore, the returns on capital in the North and South are equalized. It should also be noted that, in contrast to the modern neo-Marxist approach, intermediary goods are not taken into account in the DFS-model. The return, therefore, relates to the wage bill paid, i.e., it is a simple wage fund model.[26]

Since the rate of return is identical across the trading partners, it plays no role in determining the international distribution of production because the relative costs advantages are not affected by the uniform rate of return. To determine the trade equilibrium we can, therefore, proceed directly to Equation (3.4). If we also consider the demand side, assuming that resource owners and capital owners have the same consumption preferences, we arrive at equation Equation (3.10) which together with Equation (3.4) determines both $\bar{z}$ and $\bar{\omega}$. In the neo-Ricardian context, however, there is an overdetermination because the exogenous resource prices already predetermine $\bar{\omega}$. The overdetermination becomes visible in the DFS-model because the

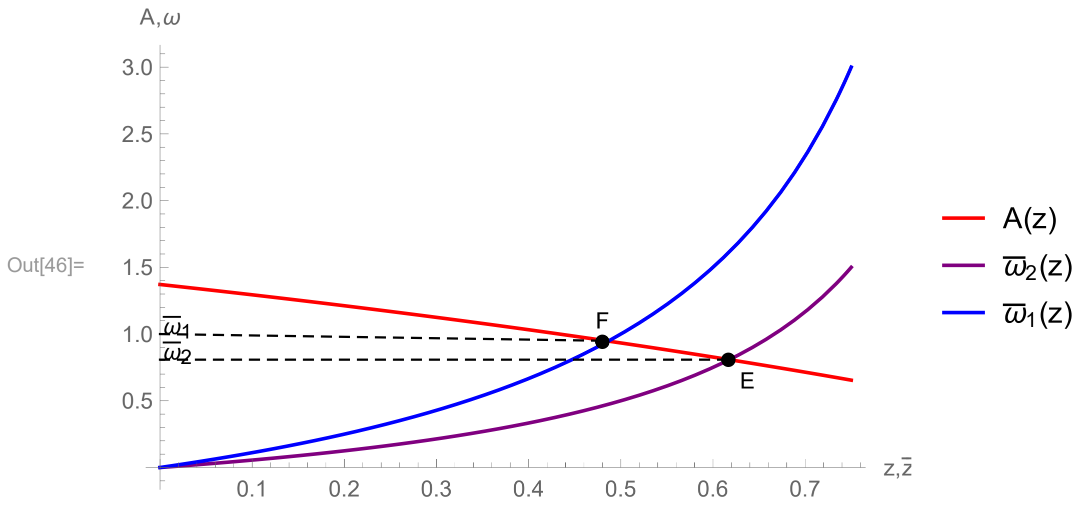
[23]See Emmanuel (1975)

[24]A more in-depth analytical exposition can be found in Evans (1984).

[25]Emmanuel (1972), p. 61

[26]Evans (1984) includes intermediate goods into the price equations (in Marxist terms: circulating capital) in the framework auf a two-country-two-goods model. Mainwaring (1980) discusses the role of intermediate goods for the unequal exchange of labor values.

goods demand side and the trade balance are taken into account in this model. In the neo-Marxist approaches to unequal exchange, the quantity relationships and, thus, the balance of trade are not taken into account because the linear price model for closed economies is applied to international trade. In these models, the quantity system and the price system are completely separated. However, it is known from the simple Ricardian foreign trade model that the terms of trade in a linear production model are also determined by demand because the production factor labor or, in our case, the natural resources are internationally immobile. Exploitation relationships, therefore, do not solely determine the exchange ratio of traded goods. Bacha (1978) has pointed out in the context of a two-country-two-goods model that the assumption of a fixed exchange of labor values - in our case the resource exchange ratio - can only prevail if there is a quantity adjustment of the resource inputs.[27] In our case, it is sufficient if the resource input in the South $\bar{R}_S$ adjusts accordingly so that the balance of trade remains balanced for each exchange ratio. This relationship can be seen in the following figure.



Source: Own illustration.

Figure 3.4: Fixed factoral terms of trade and resource use

At point F, there is a trade equilibrium with factoral terms of trade of $\bar{\omega}_1$. This corresponds to a factoral terms of trade ratio of $\bar{R}_N/\bar{R}_S$ (see Equation (3.10)). If, in the course of further exploitation of the South, the factoral terms of trade deteriorates to $\bar{\omega}_2$, a new trade equilibrium can only arise if the resource input in the South increases[28]. $\bar{R}_S$ increases so that the ω-curve runs exactly through point E. The core statement of the EUE can then be summarized as follows.[29]

Result 4 *The deterioration of the factoral terms of trade leads to a relatively greater utilisation of the South's resources. Therefore, the increased net outflow of resources*

[27]For a survey of the literature see also Ocampo (1986).

[28]We have assumed that the North leaves $\bar{R}_N$ constant.

[29]This statement is similar to the result Bacha (1978) has derived within the standard two-good-two-country model.

from the South is accompanied by increased resource exploitation in the South. Ecological unequal exchange to the disantvantage of the South and increased exploitation of South's nature thus go hand in hand.

From the perspective of labor theory of value, this conclusion is understandable. The factoral terms of trade also reflect the relative income per worker ($\omega = q_S/q_N$). However, if the theory of unequal exchange is applied to the exchange of resources, the factoral terms of trade cannot be interpreted as an indicator of an exploitative relationship, as summarized in Section (3.1). In this case, the ratio of the total income of both countries must be set in proportion, i.e., $(q_S R_S)/(q_N R_N)$. This quotient can be used to determine the ratio in which the income of the two countries is exchanged.[30] Equation (3.10) and Equation (6.16) immediately show that the income ratio is nothing other than Ψ. Thus, if the factoral terms of trade fall exogenously due to political-economic forces, this even improves the income situation in the South. A comprehensive political-economic analysis should therefore include the functional income distribution between labor, capital, and land ownership (resource ownership) in the South and North to assess exploitative relationships. The factoral terms of trade are not suitable as a measure of exploitation as long as the distribution mechanisms within both economies have not been clarified. This finding applies to both types of model, the neoclassical Ricardian foreign trade model and the ecological neo-Ricardian model, in which the factoral terms of trade are exogenously given.

Another criticism of the EUE approach is the unspoken implication that a deterioration in the factoral terms of trade results in the overexploitation of nature. The fact that an exogenous deterioration in the terms of trade leads to an increase in the use of resources does not mean that nature's regenerative capacities have been exceeded. This question can only be answered if the institutional framework of resource use is clarified.[31] The assumption of exogenous resource prices is taken from the neo-Marxist model of labour exploitation. The workers receive their fixed subsistence wage. Lewis adopted this relationship for dual economies with an agricultural subsistence sector and an industrial sector. The fixed labor wage is the result of an oversupply of labor that is offered if the wage exceeds the subsistence income. However, it is not clear whether these characteristics of the labor market in the South can simply be transferred to the resource market in the South. The neoclassical modelling approach with a fixed supply of resources at a flexible resource price approximates reality better because the extraction of natural resources is limited by capacities whose expansion requires investments. Thus, the supply of resources is presumably not completely elastic.

[30]If the ratio is to be related to per capita income, the population of both countries must also be taken into account.

[31]See e.g. Chichilnisky (1993) and Brander and Taylor (1997).

3.4 Fair trade, transfers and EUE

Beyond the neo-marxian literature there is also an extensive literature on the relation between inequality and international trade.[32] In this section, we discuss some criteria of international distributive justice and their policy instruments for its implementation within the DFS model. We show that justice-oriented trade policy should not make its instruments dependent on bio-physical flows.

In the Ricardian one-factor model, distribution problems can only relate to the endowment of factors and the ownership of technologies. When applying the model to natural factors, migration cannot be used as a means of distribution policy.[33] Thus, natural resources cannot be allocated directly to countries according to equity criteria. Their endowment is subject to geographical randomness, be it resources that are used as inputs or natural capacities for absorbing emissions and waste. However, resources can be redistributed virtually by assigning property rights[34] and the question remains as to the normative basis on which claims can be legitimized.[35] There are two opposing fundamental criteria: self-ownership and joint ownership. Applied to countries, the first principle considers a country to be the rightful owner of a natural resource because the population has legitimately appropriated it. This position implies that the appropriation is not to the detriment of others. The second principle considers the geographical distribution of natural resources across countries' territories to be (morally) random or arbitrary.[36] This view concludes that all natural resources are owned jointly by all countries (joint ownership) and gives rise to a claim by resource-poor countries to the proceeds of trade based on the utilization of resources of resource-rich countries. The issue of fair trade, therefore, does not relate to the exchange ratio of goods or virtual resource content, as in the theory of ecologically unequal exchange, but to the fair distribution of resource ownership.[37] The principle of joint ownership can also be applied to the ownership of productivity-enhancing technologies of economies.[38] Exclusive ownership claims can be legitimized if production technologies have not come to their owners by chance but due to their efforts. This also applies if technological disadvantages do not result from the systematic prevention of development opportunities. If, on

[32] See e.g. the overview of Kanbur (2015). Findlay (1982) relates philosophical fairness principles to the theory of international trade.

[33] Findlay (1982) examines the distributional effects when the labor factor is mobile (migration)

[34] One example of resource appropriation is the extensive large-scale acquisitions of agricultural land in developing countries. See for example Dell'Angelo et al. (2018).

[35] See the extensive discussion inRoemer (1996), chapter 6.

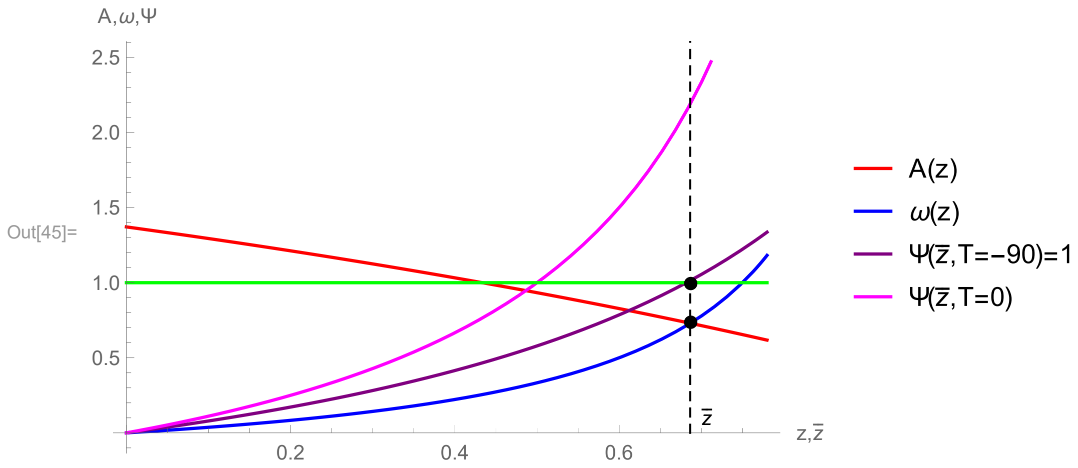
[36] The concept originates from Rawls and means that benefits that accrue to individuals or, in our case, countries through an act of arbitrariness of nature are collective property. They, therefore, belong in the set of resources that are subject to fair redistribution, provided they can be redistributed. If this is not possible, such as in the case of innate talents, appropriate compensation should be established. See the discussion in Sandel (2007), p. 153 ff.

[37] Using the equitable distribution of resources, Fleurbaey (2014) defines exploitative relations that are not based on exchange relations, for example unequal exchange of labor values, but on the distribution of resources and the ensuing income streams from the utilization of the resources.

[38] This issue can also be applied to preferences if the distribution of resources (or consumer goods) depends on preferences. Here, the question arises of whether people are responsible for their preferences. See here Roemer (1996), p. 237.

the other hand, technological differences are the result of historical randomness or power constellations, then technologies should also be jointly owned.

Before we analyze the welfare-theoretical implications of the distributive justice criteria within the framework of the DFS model, we examine the effect of distributive policy instruments. These transfers between the South and North can take place in various ways: Technology transfers, direct investments (capital transfers), the assignment of property rights to natural resources, and transfers of purchasing power. Here, we do not pursue the first two transfers further here, because they would require a model of higher complexity. We only consider the allocation of property rights that lead to corresponding transfers of scarcity rents, i.e. purchasing power. The effects of transfers have been extensively analyzed in the literature and goes back to Keynes' classic analysis.[39] In the simple, pure foreign trade models of Ricardian provenance and the multi-factor models of Heckscher and Ohlin, transfers do not change the factoral terms of trade if the preferences of the trading countries are identical. This can be shown for the DFS-model (see Section (6.4)) and is illustrated in the following figure.



Source: Own illustration.

Figure 3.5: Effects of transfers from South to North

The figure contains the two functions $A(z)$ and $\omega(z)$. The intersection point denotes the trading equilibrium $\bar{\omega}$ or $\bar{z}$ that remains unaffected by the transfer. So the net transfer of biophysical material does not change either. Only Ψ, the relative welfare of the South, changes from $\Psi(T = 0))$ to $\Psi(T = -80)$ as a result of the transfer from the South to the North.[40] The transfer $T = -80$ leads to equal welfare of both regions, i.e. $\Psi(\bar{z}, T = -80) = 1$.

Result 5 *With identical preferences, transfers do not change the factoral terms of trade, but they do change the welfare distribution. This means that a fair distribution policy is not reflected in the material flows between the South and the North.*

[39]See e.g. Jones (1975).

[40]We have assumed South's resource endowment is higher than North's. See the derivation in Section (6.4) and Section (6.5).

Thus, constructing a fair trade system should not be based on the physical net position of international trade. Distribution policy should not be linked to physical flows because there is no monotonic relationship between welfare distribution and the net ecological position of trade relations.

It remains to determine the amount of transfers with the help of equity criteria. Here, we follow Roemer's approach[41] and relate the question of justice to the distribution of natural resources and technological equipment. If the level of endowments is not the result of the deliberate efforts of the acting societies, i.e., if they are morally arbitrary, they should be collectively owned. Therefore, the trade equilibrium derived in Section (3.1) is unjust if R_S is unequal to R_N generally implying[42] $\psi(z) \neq 1$. The principle of joint ownership can be well defined and derived with the help of the Nash-bargaining approach. In the context of the DFS model, this means that natural resources by both countries can only be utilized if South and North have agreed on the distribution of ownership. Otherwise, no production is possible. Therefore, there is a negotiation game in which the threat points are zero. The utility functions of South and North for given transfer T in trade equlibrium are

$$\bar{U}_S(T) := \exp(L_S(\bar{z})) \text{ and } \bar{U}_N(T) := \exp(L_N(\bar{z})) \tag{3.12}$$

where $L_i(\bar{z}), i = S, N$ are defined in Equation (6.12) and Equation (6.13). The Nash solution, then, follows from the follwing program:[43]

$$\max_T [\bar{U}_S(T) \times \bar{U}_N(T)] \quad \Rightarrow \quad T^* = \frac{R_N - R_S\bar{\omega}}{2\bar{\omega}} \lesseqgtr 0 \tag{3.13}$$

It follows from this approach that the transfer amount should be chosen so that the incomes of both countries are equal, i.e. $R_N - \bar{\omega}T = (R_S + T)\bar{\omega}$, which also results in equality of welfare, i.e. $\psi = 1$. This extremely egalitarian result follows from the principle of joint ownership. Although the technologies are different and are owned exclusively by the two groups of countries, welfare equality prevails. This is because the two threat points are zero, i.e., without agreement, there is no production and no consumption in autarky. Of course, this approach can only serve as a normative reference point, as no country can be denied the retreat position of autarky resulting from the principle of sovereignty. The determination of an acceptable transfer perceived as fair will, therefore, have to mediate between the principles of equity and sovereignty what can be referred to as weak joint ownership.

For example, if we consider both the principle of joint ownership and that of sovereignty equally, we arrive at a transfer determination that takes into account the autarky starting point of both countries. The South and North remain in autarky if no agreement is reached on a possible transfer. The corresponding Nash bargaining approach is:

$$\max_T [(\bar{U}_S(T) - \bar{U}_S(A)) \times (\bar{U}_N(T) - \bar{U}_N(A))] \tag{3.14}$$

[41] See Roemer (1996), chapter 6, for a bargaining model where labor productivity are uneqally distributed.

[42] We cannot exclude the case that the technologies of both countries are such that for an specific unequal resource endowment $\psi = 1$.

[43] For the derivation see Section (6.5))

where $\bar{U}_i(A)), i = \{S, N\}$ are the welfare levels in the case of autarky. Here, the explicit determination of the optimal and fair transfer is only possible numerically in the DFS-model. However, for the normative discussion it is sufficient to describe the qualitative properties of the solution. In contrast to pure joint ownership, the negotiation outcome here does not provide for an egalitarian solution $\bar{U}_S(T) = \bar{U}_N(T)$. The two negotiating partners agree on a transfer that provides equality in the trade's welfare gains, i.e.

$$(\bar{U}_S(T) - \bar{U}_S(A)) = (\bar{U}_N(T) - \bar{U}_N(A)) \tag{3.15}$$

With different starting positions in autarky, this principle means that welfare in both blocs differs even after a transfer has been implemented.

The combined principle[44] of joint ownership and sovereignty (autarky as starting point and fall back position) legitimizes different starting positions as morally justified. As a rule, the transfer calculated from the equation does not equal zero. This means that pure trade equilibrium without an accompanying transfer is considered unfair from this normative perspective, although the approach is also committed to self-ownership of initial resource endowments. This is because the bargaining approach contains an element of equality. The distribution of trade benefits will not be left to the mechanics of supply and demand alone, but the welfare gains of North and South will be distributed equally. The positive welfare effect of trade resulting from specialization in comparative cost advantages is joint ownership. Finally, it should be emphasized once again, whichever principle is considered morally acceptable, strong joint ownership or the mediated principle of weak joint ownership, both relate the issue of fair trade to the distribution of natural resources and technologies and not to the exchange ratio of ecological values.

4 How false measurement leads to flawed policies

We have seen above (Section (3)) that the normative objective of balanced terms of trade in material terms does not promote two recognized strategies of policy in North-South relations, namely overcoming the technological gap and transfers of purchasing power, but may even contradict them. This also applies to all other forms of development cooperation that are not related to material flows, e.g. cooperation for human rights and freedoms, democracy and the rule of law. One would think that at least policies concerning the link between environment and society would be supported by materially balanced trade flows and material flow analysis. We show in closing that the objective of an ecologically balanced trade (EBE) is also misleading in entirely environmental and resource economic contexts.

The ecological perspective on trade theory defines unfair trade as a constant flow of resources from less developed to more developed countries or persistent transfer of environmental impacts for the latter which negatively affects their development capacity (Althouse et al. (2023)). The goal is to minimize Domestic Natural Consumption (DMC) as the sum of Domestic Extraction (DE) and the trade balance of

[44] The combination of both principles is an extensions of Roemer's principle of joint ownership. See Roemer (1996), chapter 6.

material imports and exports. Balanced trade lies at the heart of the EUE narrative. Imports and exports should be materially balanced, not only monetarily but also physically. On the one hand, this implies an ethical allocation of responsibility for the release of environmentally damaging substances (e.g. carbon dioxide) in the final demand, regardless of where this occurs. This judgment can be followed. The question remains: Is the theory of EUE and the normative stipulation of balanced material flows sensible and appropriate? Here too, the bio-physical indicators used are inappropriate and meaningless. They can even lead in an undesirable direction. Example: A country in the global South with a rich supply of spices trades in exchange for services from a country in the global North. The bio-physical trade balance is unfavorable for the country of the South (see Figure (3.1)). Nevertheless, the indicator of bio-physical outflow does not show ecological exploitation since in the trade equilibrium the relative welfare distribution of the South is better than for the case of factoral terms of trade equal to one (no net-outflow), as has been shown above (Section (3.1)). Hence, the pure exchange of goods is not exploitative per se or *"extractivist"* in the sense of Alonso-Fernández and Regueiro-Ferreira (2022).

This can be further elaborated by a thought experiment: Assume a world in which North and South have a strong joint ownership of resources.[45] Assume further that the factoral terms of trade in the starting position are equal or almost equal (point F in Figure (3.1)). If, by an act of god, the resource endowment were to be shifted in favor of the South (point E in Figure (3.1)), this would significantly increase the welfare of the South in absolute and relative terms (moving upwards along the purple line). However, precisely this movement in favor of the welfare of the South would have to be described as a negative development in the sense of the EUE theory.

Overall, it can be seen that the net outflow indicator of the EUE theory is completely tautological. The measurement method used, the material flow analysis, diagnoses in a first step that the South is being exploited whenever the factoral terms of trade deviate negatively from a 1:1 resource exchange. The material net outflow is then calculated and its negative sign is used to confirm the ecological exploitation defined in this way. The theory therefore follows the measurement and not vice versa.

The failure of sensible policies to follow the principle of the balanced net position can be seen in the history of the theory of virtual water trade. As shown above (Chapter 2), virtual water trade was still seen in the 1980s as a measure to improve global water use efficiency and as a means to prevent water wars (Allan (2003)). With the development of the water footprint as a measure, this turned into a demand for a *"measurable increase in the fairness of resource use"*. The water consumption and water footprint of nations should be minimized, or at least levelized. Each nation would thus be required to bind its producers and consumers to the permissible amount of actual and virtual water consumption or, if necessary, to make a compensation payment to other countries for an increased national water footprint

[45] This thought experiment assumes a reference point that all inhabitants of the earth (here designated by the South and the North) have the same claims to scarce resources, in which case no claim to complete ownership can be derived from the geographical appropriation. See Roemer (1996).

according to the concept of *"water neutrality"* of Hung (2002). The avoidance of international water conflicts, which was originally the aim of virtual water trade, has thus been pushed into the background of international water policy, although it is precisely this that should be seen as increasing welfare for the global community.

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2. Author contributions (all co-authors shall be listed using their initials):

   GM: Conception of the work; redesign of the DFS model for EUE purposes; formal analysis and interpretation; drafting of the work

   RS: Conception of the work; formal analysis and interpretation; substantive revision and editing
3. Conflict of interest: The authors declare no conflict of interest.

6 Appendix

6.1 Derivation of the demand function

To derive the demand functions we follow DFS and assume identical utility functions in both, North and South, specified by a Cobb-Douglas function.

$$U := \prod_{0}^{1} g(z)^{dz} = \exp(\int_0^1 \ln(g(z))dz) \tag{6.1}$$

where $g(z) = c(z)^{b(z)}$, $c(z)$ being the demand for product z and $b(z)$ being the partial elasticities with respect to the respective prices. We assume also $\int_0^1 b(z) = 1$ and [46] $b(z) = b =$ constant. Thus, $b(z) = b = 1$. Since the product space is continous Equation (6.1) depicts total utility over the product space as product integral that can be transformed to the expression of the right hand side (see Ospina-Holguín (2017), theorem 10).

To derive the demand functions U has to be maximized with respect to the budget constraint

$$\int_0^1 p(z)c(z) \leq Y \tag{6.2}$$

where Y is income and $p(z)$ are the product prices. Recalling equation (6.1), this task can be achieved by maximizing $\int_0^1 \ln(g(z))dz$ s.t. Equation (6.2), which is the continuous version of the usual standard procedure as presented in textbooks leading to the demand functions in Equation (3.5).

[46]This assumption is similar to that of the Dixit-Stiglitz model of the demand for product variety based on a CES-utility function.

6.2 Factoral terms of trade and biophysical flows

The amount of resources embodied in the commodities transferred from the North to the South, i.e. the amount of resources (virtually) imported to the South, is

$$\int_{\bar{z}}^{1} a_N(z)c_S(z)dz = \int_{\bar{z}}^{1} a_N(z)\frac{b(z)\bar{R}_S q_S}{a_N(z)q_N}dz = (1-\theta(\bar{z}))b\bar{R}_S\bar{\omega} \tag{6.3}$$

where $\bar{\omega} = \omega(\bar{z})$. Similar, the embodied resources in the products exported from the South to the North is

$$\int_{0}^{\bar{z}} a_S(z)c_N(z)dz = \int_{0}^{\bar{z}} a_S(z)\frac{b(z)\bar{R}_N q_N}{a_S(z)q_S}dz = \theta(\bar{z})b\frac{\bar{R}_N}{\bar{\omega}} \tag{6.4}$$

Dividing resources imported, i.e. Equation (6.4), by resources exported, i.e. Equation (6.3) , yields the factoral terms of trade:

$$\text{tot}_f = \left[\frac{(1-\theta(\bar{z}))\bar{R}_S}{\theta(\bar{z})\bar{R}_N}\right]\bar{\omega}^2 = \bar{\omega} \tag{6.5}$$

where the last step follows from Equation (3.10), i.e. $\bar{\omega} = \frac{\theta(\bar{z})}{1-\theta(\bar{z})}(\bar{R}_N/\bar{R}_S)$.

6.3 Derivation of the utility-ratio function

The derivation of the two ratios requires the calculation of the indirect utility functions by inserting the optimal consumption according to Equation (3.5) into the utility function Equation (6.1). We first calculate the logarithm

$$L_J = \int_0^1 [b(z)\ln(\frac{b(z)Y_J}{p(z)})]dz, \;\; J = \{S, N\} \tag{6.6}$$

and then carry out the transformation $\exp(L_J)$ whereby we maintain $b(z) = b =$ constant $= 1$.

In the trading equilibrium, the integral must be split into the two intervals $[0, \bar{z}]$. x and $[\bar{z}, 1]$, $\bar{z}$ being the equilibrium specialization between the South and the North (see Figure (3.1)). If we insert Equation (3.1) and income $Y_J = q_J\bar{R}_J$, $J = \{S, N\}$ we obtain for the South

$$L_S(\bar{z}) = \int_0^{\bar{z}} [b\ln(\frac{b\bar{R}_S}{a_S(z)})]dz + \int_{\bar{z}}^1 [b\ln(\frac{b\bar{R}_S\bar{\omega}}{a_N(z)})]dz \tag{6.7}$$

where $\bar{\omega} = \bar{q}_S/\bar{q}_N$ are the equilibrium factoral terms of trade at $z = \bar{z}$.

Similar, we can find for the North

$$L_N(\bar{z}) = \int_0^{\bar{z}} [b\ln(\frac{b\bar{R}_N}{a_S(z)\bar{\omega}})]dz + \int_{\bar{z}}^1 [b\ln(\frac{b\bar{R}_N}{a_N(z)})]dz \tag{6.8}$$

If we subtract L_N from L_S, we get

$$L_S(\bar{z}) - L_N(\bar{z}) = \int_0^{\bar{z}} [b\ln(\frac{\bar{R}_S\bar{\omega}}{R_N})]dz + \int_{\bar{z}}^1 [b\ln(\frac{\bar{R}_S\bar{\omega}}{R_N})]dz = \int_0^1 [\ln(\frac{\bar{R}_S\bar{\omega}}{R_N})]dz \tag{6.9}$$

and, utilizing Equation (6.1) and Equation (3.10), thus

$$\Psi(\bar{z}) = \exp(L_S(\bar{z}) - L_N(\bar{z})) = \exp(\int_0^1 [\ln(\frac{\bar{R}_S\omega(\bar{z})}{\bar{R}_N})]dz) = \frac{\theta(\bar{z})}{1-\theta(\bar{z})} \tag{6.10}$$

6.4 Effects of the transfer on the ω- and Ψ-function

To derive the effects of a transfer T on the factoral terms of trade Equation (3.8) must be modified to

$$\int_0^{\bar{z}} \left[b(z)\frac{Y_S + T}{q_S} + b(z)\frac{Y_N - T}{q_S} \right] dz = \bar{R}_S \tag{6.11}$$

Since we assumed identical preferences in the South and the North it is immediately clear that T cancels out and, hence, does not affect the factoral terms of trade ω defined in Equation (3.10). Thus, the intersection of $A(z)$ with $\omega(z)$ determining the trade equilibrium $\bar{z}$ is also independent of T.

To derive the effect of T on the welfare distribution Ψ insert T into Equation (6.7) for $J = \{S, N\}$ yielding

$$L_S(\bar{z}, T) = \int_0^{\bar{z}} [b \ln \left(\frac{b(\bar{R}_S q_S + q_S T)}{a_S(z) q_S} \right)] dz + \int_{\bar{z}}^1 [b \ln \left(\frac{b(\bar{R}_S q_S + q_S T)}{a_N(z) q_N} \right)] dz \tag{6.12}$$

$$L_N(\bar{z}, T) = \int_0^{\bar{z}} [b \ln \left(\frac{b(\bar{R}_N q_N - q_S T)}{a_S(z) q_S} \right)] dz + \int_{\bar{z}}^1 [b \ln \left(\frac{b(\bar{R}_N q_N - q_S T)}{a_N(z) q_N} \right)] dz \tag{6.13}$$

where we have inserted $Y_J = q_J \bar{R}_J$, $J = \{S, N\}$ and expressed the transfer in units of the resources in the South. In the following we suppress the variable $\bar{z}$ since the trade equilibrium is indpendent of T. Thus, $L_i(T) := L_i(\bar{z}, T), i = \{S, N\}$.

Subtracting Equation (6.13) from Equation (6.12) yields

$$L_S(T) - L_N(T) = \int_0^{\bar{z}} [b \ln \left(\frac{(\bar{R}_S q_S + q_S T)}{\bar{R}_N q_N - q_S T} \right)] dz + \int_{\bar{z}}^1 [b \ln \left(\frac{(\bar{R}_S q_S + q_S T)}{\bar{R}_N q_N - q_S T} \right)] dz \tag{6.14}$$

Utilizing the definition of the factoral terms of trade in equilibrium $\omega = q_S/q_N$ and recalling $b = 1$ yields

$$L_S(T) - L_N(T) = \ln \left(\frac{(\bar{R}_S + T)\bar{\omega}}{(\bar{R}_N - T\bar{\omega})} \right) \tag{6.15}$$

where $\bar{\omega}$ is defined in Equation (3.10). Utilizing Equation (6.1) we arrive at

$$\Psi(T) = \exp(L_S(T) - L_N(T)) = \frac{(\bar{R}_S + T)\bar{\omega}}{(\bar{R}_N - T\bar{\omega})} \tag{6.16}$$

6.5 Derivation of the equitable transfer

We transform the maximization program (3.13) by taking the logarithm of the objective function. This leads to the program

$$\max_T [L_S(T) + L_N(T)] \tag{6.17}$$

where $L_S(T)$ are defined in Equation (6.12) and Equation (6.13). Both functions can be rearranged to

$$L_S(T) = \Lambda_S(T) + \int_{\bar{z}}^1 \left[b \ln \left(\frac{\omega(\bar{z})}{A(z)} \right) \right] dz \tag{6.18}$$

where $\Lambda_S(T) = \int_0^1 \left[b \ln\left(\frac{b(\bar{R}_S q_S + q_S T)}{a_S(z) q_S}\right)\right] dz$ and

$$L_N(T) = \Lambda_N(T) + \int_0^{\bar{z}} \left[b \ln\left(\frac{A(z)}{\omega(\bar{z})}\right)\right] dz \tag{6.19}$$

where $\Lambda_N(T) = \int_0^1 \left[b \ln\left(\frac{b(R_N - \omega(\bar{z})T)}{a_N(z)}\right)\right] dz$. Notice, that the second expressions on the right hand sides do not depend on T due to the invariance of the trading equilibrium with respect to the transfer.

The optimal T from Equation (6.17) is charaterized by the first order condition[47]

$$L_N^{'}(T) + L_N^{'}(T) = 0 \;\Rightarrow\; \Lambda_S^{'}(T) + \Lambda_N^{'}(T) = 0 \;\Rightarrow \tag{6.20}$$

where $\Lambda_S^{'}(T) = 1/(\bar{R}_S + T)$ and $\Lambda_N^{'}(T) = -\bar{\omega}/(\bar{R}_N - \bar{\omega}T)$. Rearranging Equation (6.20) yields T^* in Equation (3.13).

The first order condition of Equation (3.14) is

$$\bar{U}_S^{'}(T)(\bar{U}_N(T) - \bar{U}_N(A)) = \bar{U}_N^{'}(T)(\bar{U}_S(T) - \bar{U}_S(A)) \tag{6.21}$$

where $\bar{U}_i(A), i = \{S, N\}$, indicates the utility levels in autarky. Utilizing Equation (3.12), Equation (6.18) and Equation (6.19) yields

$$\frac{L_S^{'}(T)\exp(L_S(T))}{L_N^{'}(T)\exp(L_N(T))} = \frac{\Lambda_S^{'}(T)\exp(L_S(T))}{\Lambda_N^{'}(T)\exp(L_N(T))} = \frac{(\bar{U}_S(T) - \bar{U}_S(A))}{(\bar{U}_N(T) - \bar{U}_N(A))} = 1 \tag{6.22}$$

By inserting $\Lambda_S^{'}(T)$, $\Lambda_N^{'}(T)$ and Equation (6.15) into Equation (6.22) it can verified that the ratios are one. This proofs Equation (3.15).

7 References

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[47]It is straightforward to show that the second order is fulfilled because both functions are concave with respect to T.

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