Matter and regulation: socio-metabolic and accumulation regimes of French capitalism since 1948

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Abstract

This paper aims at integrating macroeconomic and institutional analyses of long run dynamics of capitalism with material flow analysis. We investigate the links between accumulation and socio-metabolic regimes by studying French capitalism from a material perspective since 1948. We characterize its social metabolism both in production- and consumption-based approaches. We show that the periodization of accumulation regimes in terms of Fordism and Neoliberalism translates into material terms. The offshore materiality of Neoliberalism partly substitutes for and partly complements the more domestic materiality inherited from Fordism. The transition phase between the two socio-metabolic regimes clearly corresponds to the emergence of the offshoring-financialization nexus of French capitalism indicating the shift from the fordist accumulation regime to the neoliberal accumulation regime. Acknowledging that socio-metabolic regimes have their own logic, we highlight strong inter-linkages between accumulation and material dynamics and discuss how materials may be instrumental in shaping accumulation regimes. This work therefore illustrates the relevance of combining institutional macroeconomics with methods and approaches derived from Ecological Economics.

Keywords: Material Flow Analysis; Material footprint; Socio-metabolic regime; Financialization; Offshoring; Accumulation regime

JEL: E02; O11; O13; P16; P18; Q57

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1 Introduction

Material extraction has more than tripled globally between 1970 and 2010 at a time where both population and economic growth slowed down. Global primary material use is expected to double by 2060, alongside the growth of in-use material stocks (e.g. building, machines, infrastructures). This ever widening material basis of our societies has potentially huge environmental consequences, e.g. natural resources exhaustion, additional greenhouse gases emissions or biodiversity loss. This is all the more concerning as material efficiency — the amount of primary materials required per unit of economic activity — has declined globally since 2000 due to production offshoring from very to less material-efficient countries and massive building of infrastructures in emerging countries, especially China (OECD, 2019; Schandl et al., 2018; Wiedenhofer et al., 2019).

Yet, key economic indicators like the gross domestic product or measurement tools like national accounting remain largely disconnected from the physical basis of our societies. This disconnection results in the dematerialization of the representation of the economy (Pottier, 2014). At a time where planetary boundaries are all being exceeded (Steffen et al., 2015), it is therefore urgent to integrate a physical dimension to the understanding of accumulation dynamics and to the long run analysis of capitalism (Görg et al., 2020).

Despite calls for integrating political ecology, political economy, environmental history and ecological economics (Muradian et al., 2012), few studies have undertaken to investigate capital accumulation dynamics and biophysical flows together. In this paper, we attempt at comprehending in an integrated manner the socio-metabolic and accumulation regimes of French capitalism since 1948. To do so, we bring together two strands of literature that had yet to converse: Material Flow Analysis (MFA) and Regulation Theory (RT).

RT provides an analytical framework to analyse the long run dynamics as well as the historical and spatial diversities of capitalism through accumulation regimes. An *accumulation regime* consists of "*the set of regularities that ensure the general and relatively coherent progress of capital accumulation, that is, which allow the resolution or postponement of the distortions and disequilibria to which the process continually gives rise*" (Boyer and Saillard, 2002, p. 334). These regularities are given kinds of production organization, income distribution and composition of demand combining into a coherent regime through their dynamic compatibility (Aglietta, 2015; Boyer, 2015). The term *regulation* (in RT and in the title) refers to the institutional forms embodying social compromises and thus enabling a coherent reproduction of the economic system over time through setting patterns of individual and collective behaviours. The institutional forms combine together in the *mode of regulation* supporting the accumulation regime and *regulating* it.

MFA offers a physical perspective on economies. It quantifies social metabolism, that is the way societies organize their exchanges of matter and energy with their natural environment. Social metabolism refers to the physical throughput of the economic system in terms of the energy and materials associated with economic activities, either as direct or indirect inputs and wastes.

socio-metabolic regimes correspond to human modes of subsistence, "*a dynamic equilibrium of a system of society-nature interaction*" (Fischer-Kowalski and Haberl, 1993; Haberl et al., 2016).

Until recently, RT was notoriously blind to environmental issues and natural resources dynamics (Cahen-Fourot, 2020; Chester, 2010; Zuindeau, 2007) while MFA has yet to integrate its approach into a political economy of capitalism. Nonetheless, both RT and MFA privilege long term analyses and attempt at identifying periodization of, respectively, accumulation and socio-metabolic regimes, their crises and the associated transitions, mainly from a methodological nationalist perspective.

Two distinct accumulation regimes have been identified in the post-war era in France: Fordism, from the early years of post-war recovery to the mid-seventies and Neoliberalism from then onwards. Fordism can be characterized by high productivity gains supporting a social compromise between labour and capital in favour of labour resulting into strong redistributive institutions such as the welfare-state and social security, long term employment relations and an accumulation process led by domestic mass consumption. Neoliberalism is characterized by the progressive dismantling and replacement of the welfare by a market regulator state, the flexibilization of employment relations and liberalization of goods, services and financial flows and the rise of finance as a dominating sector of the economy and of financial motives as the leading principle of non-financial corporate governance (Boyer, 2015; Duménil and Lévy, 2014; Harvey, 2014; Husson, 2012; Lazonick and O'Sullivan, 2000).

Fordism and Neoliberalism also translate into biophysical terms. In high income countries, fordism can be characterized as an extensive energy regime with decreasing efficiency but fastly increasing quantity integrated into the production process and supporting high labour productivity gains. Neoliberalism exhibits a rising energy efficiency with a strong relocation of energy use abroad accompanying the restoration of the capital share in the distribution of value added. Beyond energy, correspondence between the socio-metabolic and accumulation regimes of French capitalism in the post-war era has been shown for production-based material flows (Cahen-Fourot and Durand, 2016; Magalhães et al., 2019).

This paper pertains to a research program in its infancy and is thus mainly descriptive. Still, our research question is twofold. First, it is to confirm the common temporality between accumulation and socio-metabolic regimes of French capitalism in the post-war period by going beyond methodological nationalism through integrating material footprint data (Wiedmann et al., 2015). Second, it is to discuss the dialectical relation between accumulation and socio-metabolic regimes to understand the interdependencies and mutual influences that may explain their common dynamics.

In the reminder of this paper, we first provide in section 2 a short methodological introduction to MFA. We then present data to characterize the fordist and neoliberal socio-metabolic regimes and to approach the internationalization of French capitalism in a physical perspective. In section 3, we draw from this new perspective on internationalization and discuss accumulation regimes and the shift from Fordism to Neoliberalism. In section 4, we investigate possible causalities relating accumulation and socio-metabolic regimes in discussing the role of material in economic and political processes. We conclude by pointing out some limits and perspectives of this work.

2 Fordist and neoliberal socio-metabolic regimes: from an extensive domestic to an extensive offshore materiality

This section shows to what extent the shift between Fordism and Neoliberalism translates into material terms. We first recall the methodology of MFA and explain the need of the consumption-based approach. We then describe the main material flows tendencies. First, we examine absolute and relative material consumption at the aggregate level. Second, we deepen our description of socio-metabolic regimes by scrutinizing disaggregated data. Finally, we highlight the growing offshoring of material use.

2.1 Material flow analysis: a methodological introduction

MFA most often focuses on the domestic scale, for which long term statistics exist (Eurostat, 2018). Common indicators are domestic extraction (DE), imports (I), exports (E), physical trade balance ($PTB = I - E$) and the domestic material consumption ($DMC = DE + PTB$). The material intensity (MI) of an economy corresponds to the *DMC-to-GDP* ratio (see table 1). It is worth recalling that DMC adds flows of a very different nature: domestic extraction refers to raw materials whereas trade flows are a mix of raw and manufactured commodities. Some (low-income) extractive countries have therefore a much higher DMC per capita than high income countries. For instance, this can lead to the (wrong) conclusion that Chile consumes three times more material per capita than France or Germany[1]. DMC is generally the main indicator to assess national material dynamics. Many industrialized countries have instituted policies (Giljum et al., 2015; OECD, 2019; Wiedmann et al., 2015) encouraging 'dematerialization' by setting decreasing material intensity targets (e.g until recently MI was considered a key indicator of the EU sustainable development and Europe 2020 strategies). However, DMC's methodological nationalism entails blindness to indirect material flows generated abroad to satisfy a country's final demand.

Indirect flows are relevant measures of environmental load displacement because they remain in the exporting country but are necessary for the provision of exports (Dittrich et al., 2012). Since production and consumption in high income countries are increasingly dependent on material and energy resources from other world regions[2], environmental impacts have been

[1] Respectively around 43t/cap and 14t/cap in 2009 (Giljum et al., 2014, Table 1). Chile provides an interesting example as the leading world copper supplier: "*each ton exported by Chile needs around 25 tonnes of indirect flows that remain in the country in the form of waste and emissions*" (Muñoz et al., 2009, p. 888).

[2] Between 1990 and 2005, world trade volumes in products increased by 5.8% annually, while production only grew by 2.5% per year. Growth in trade was the highest for manufactured products (6.4%), followed by agricultural products (3.8%) and fuels and mineral products (3.5%) (Giljum et al., 2015).

increasingly approached through the whole ecological cost — the footprint — of material use and greenhouse gases emissions (Peters, 2008; Wiedmann et al., 2006).

The fundamental idea of the consumption-based approach is to allocate all the environmental responsibility to the final consumer. For material flows, this involves switching from DMC to the material footprint (MF) to take into account the raw material equivalents (RMEs) — that is not only materials actually contained in imports but also upstream material flows required along the whole production chain. Material footprint is defined as (Wiedmann et al., 2015)

$$MF = DE + RTB$$

where *RTB* is the *raw trade balance* that is raw material equivalents of imports minus raw material equivalents of exports. It is important to note that the concept of RME refers only to "used materials" — that is, those material flows that enter economic processes. The other component of these indirect flows, so-called unused extraction[3], is not included in RME and, despite its ecological relevance, is not considered here. Material inputs included in RME are therefore necessary to produce an output. A certain portion of such inputs, however, is embodied in the final outputs, whereas the rest of the material is dissipated along the production chain or recycled.

The difference between DMC and MF can be huge for metal-exporting countries (with MF < DMC) and high income industrialized countries (with MF > DMC; except for Australia). This change is particularly important for Europe, the region with the highest share of materials embodied in imports (Giljum et al., 2015). Bruckner et al. (2012, table 5) show that MF was 49% higher than DMC in 2005 for France. A final motivation to adopt a material footprint perspective for France is the steep increase from 15% in 1948 to over 50% in 2015 of the amount of imports compared to domestic extraction (*I/DE*) (Magalhães et al., 2019).

To estimate RME, it is necessary to trace material flows through the production system into domestic or foreign final consumption. Different methods exist to compute the material footprint of a country (Eurostat, 2015; Lutter et al., 2016). Multi-Regional Input Output (MRIO) models permit to study and quantify the dependency of countries regarding imports from other parts of the world (Giljum et al., 2015). Unfortunately, these data usually do not go back further than 1990. As for the bottom-up coefficient approach, it is inappropriate for our macroeconomic scale. Indeed, it is very hard to construct solid coefficients for a large number of especially highly processed products (Lutter et al., 2016), particularly for a long period. Moreover, we prefer not to implement a hybrid method (MRIO-coefficient approach) that bears the risk of being too opaque. Our production- and consumption-based historical time series combine the novel long term domestic material flow data for France from Magalhães et al. (2019) with data from the Eora input-output database (Lenzen et al., 2013). All details on data and time series

[3] Upstream material flows associated with imports are called indirect flows. Hidden flows of domestic origin are called domestic unused extraction. These flows are "*soil and rock excavated during construction or overburden from mining, the unused by-catch in fishery, the unused parts of the straw harvest in agriculture or natural gas flared or vented at the extraction site*" (Eurostat, 2018, p. 19).

construction can be found in the appendix[4]. Table 1 sums up the main MFA concepts.

acronym	unit	meaning / definition
DE	t	*Domestic Extraction*
$PTB = I - E$	t	*Physical Trade Balance*
$DMC = DE + PTB$	t	*Domestic Material Consumption*
RME_{imp}	t	Raw Material Equivalent: Upstream material requirements of imports
RME_{exp}	t	Raw Material Equivalent: Upstream material requirements of exports
$RTB = RME_{imp} - RME_{exp}$	t	*Raw Trade Balance*
$MF = DE + RTB$	t	*Material Footprint* (or *Raw Material Consumption*)
$MI = DMC/GDP$	t per US$	*Material Intensity*: efficiency of material use
$AMI = MF/GDP$	t per US$	*Adjusted Material Intensity*: efficiency of material use corrected for MF
$MP = GDP/DMC$	US$ per t	*Material Productivity*

Table 1: t = ton. Note that MF is also termed RMC (*raw material consumption*).

In what follows, we first describe material dynamics at the aggregate level, considering absolute material consumption and the material intensity of the gross value added (GVA)[5]. We then disaggregate into MFA's four main categories: biomass, metal, non-metal and fossil fuel.

2.2 An aggregate material view at French capitalism

Figure 1 illustrates the aggregate material consumption of French capitalism since 1948. It is, to the best of our knowledge, the first long term comparison of material consumption in production- and consumption-based approaches for France.

[4]While beyond the scope of this paper, it is worth mentioning the new approach suggested by Piñero et al. (2019). They combine MFA and a global value chains (GVC) approach to allocate environmental responsibility based on the value added each country and sector appropriate along the chain. An interesting result is that the consumption-based responsibility is lower than the GVC-based one for Germany and France since 1990.

[5]Here we consider GVA at factors cost as it is more accurate to compare the distribution of value added between labour and capital as we do in section 3. GVA at factors cost = compensation of employees + gross operating surplus + other subsidies on production − other taxes on production. Value added is thus comprehended as the sum of payments to use primary inputs (e.g. labour and capital) (Miller and Blair, 2009).

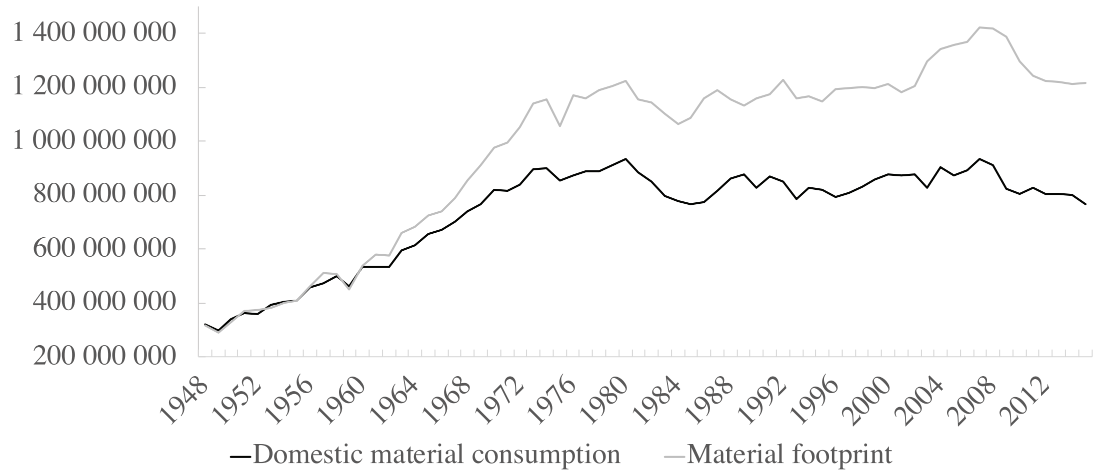

Figure 1: Domestic material consumption and material footprint in tonnes from 1948 to 2015. Sources: Lenzen et al. (2012, 2013); Magalhães et al. (2019) and authors' computations.

This figure indicates no dematerialization of French capitalism despite technological improvements and the shift of production toward services. It confirms that accumulation regimes as identified by RT have their counterpart in terms of socio-metabolic regimes[6]. We observe a clear break in the 1970s, as already observed by Wiedenhofer et al. (2013) and Cahen-Fourot and Durand (2016) for energy. The shift between Fordism and Neoliberalism in the 1970s appears as a stabilization of material consumption at the domestic scale and as an increasing offshoring as indicated by the footprint trajectory. Moreover, the divergence of the two curves that emerges in the mid-1960s highlights the importance of the footprint perspective. These curves follow a very similar path up until the end of the 1960s and shift apart at the onset of the globalization era. Both curves exhibit an increasing trend up until the late 1970s. DMC then shows a fluctuating yet flat trend afterwards, whereas the MF curve keeps increasing (although slower). All series experience another shift in the years 2007-2009 at the outburst of the global financial and economic crisis. Trajectories did not then come back to their previous trends as the figure shows. As of today, it is still unclear whether this is due to evolutions in production processes and structures or to the ongoing consequences of the crisis[7]. MF grew 4-fold since 1948, from 316 Mt[8] to 1217 Mt in 2015 (the population then rose from 41.1 to 66.4 million), reaching a peak of 1420 Mt just before the financial crisis of 2008.

[6]Initially three main socio-metabolic regimes were identified in human history: hunter-gatherers, agriculturalists, and industrial society (Fischer-Kowalski and Haberl, 1997). These *longue durée* regimes make sense from a pure metabolic point of view but may hidden historical variations due to capitalist development. In this regard, our paper can be seen as a deepening of the understanding of the quantitative and qualitative variations in the industrial society socio-metabolic regime for France in the after-war period.

[7]Kovacic et al. (2018) show that no major change occurred in the use of energy in the decade following the financial and economic crisis. Using a structural measure of inter-sectoral dependencies, Cahen-Fourot et al. (2020) also show the key importance of natural resources and raw materials for 18 European countries in 2010.

[8]One megatonne (Mt)=10^6 tonnes (t).

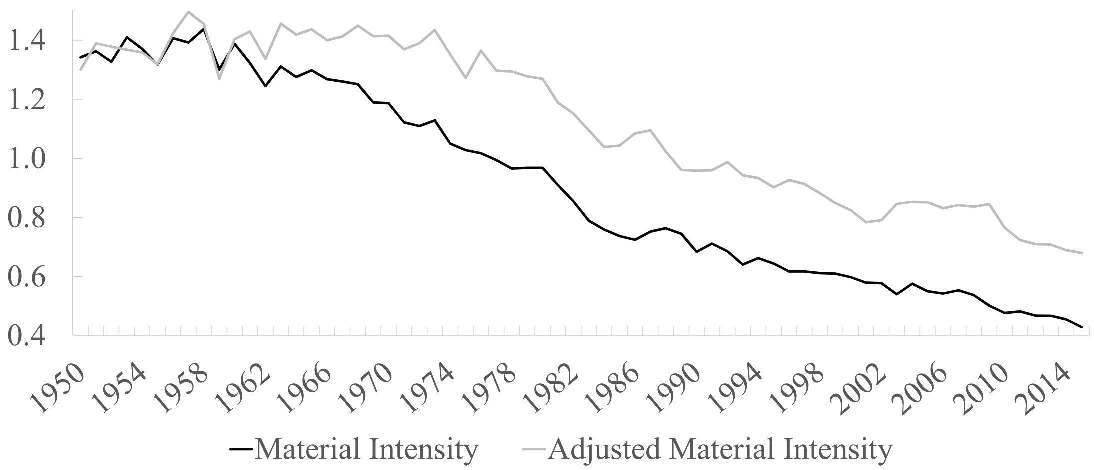

Figure 2: Domestic and footprint adjusted material intensity of GVA at factors cost in kilo per 2010 euro. Sources: authors' computations from Lenzen et al. (2012, 2013); Magalhães et al. (2019) and OECDStat data.

At the aggregate level, one can observe in figure 2 a long term relative decoupling for both approaches: a decrease of MI from 1958 onwards and of AMI from 1973 onwards. RT periodization in terms of Fordism and Neoliberalism corresponds to both MF and AMI trajectories at the aggregate level.

2.3 A disaggregate material view at French capitalism

The disaggregate level reveals more diverse dynamics. As can be seen on figure 3, the shift in the absolute material trajectory of French capitalism between Fordism and Neoliberalism translates into the disaggregated material categories for DMC but less so when looked at through MF.

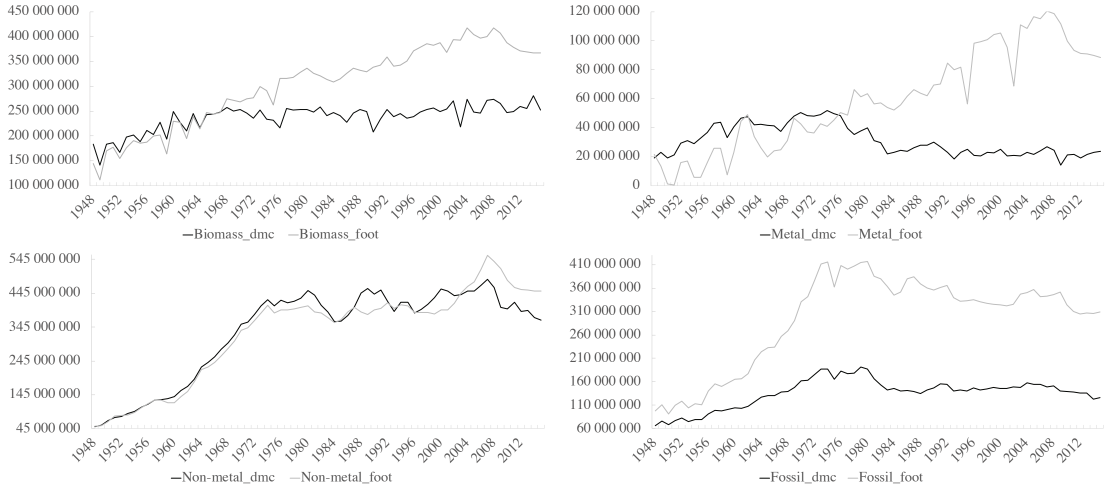

Figure 3: DMC and MF for biomass, metal, non-metal and fossil fuel. All data are in tonnes from 1948 to 2015. Sources: authors' computations from Lenzen et al. (2012, 2013); Magalhães et al. (2019).

In the DMC perspective, we observe clear shifting trends for all curves in the mid- and late-1970s. Biomass continuously increases since 1948 but with a much flatter shape after the twilight of Fordism in the late 1960s. Non-metallic minerals acknowledge the strongest increase, with an average annual growth of 8.7% for 25 years (table 2). Metal consumption stops increasing and experiences a continuous decrease since the end of Fordism while non-metal consumption strongly oscillates but does not exhibit an increasing trend after Fordism. Fossil fuel consumption reaches a maximum in 1980, after the second oil crisis, then sharply decreases and remains stable for 20 years. The fossil fuel DMC has decreased further after the 2008 crisis.

MF offers a slightly different picture. Biomass and metal continuously increase, respectively from 1948 and the early 1960s, indicating no shift between Fordism and Neoliberalism. Contrariwise, non-metal and fossil fuel footprints indicate again a break in the mid-1970s. Their behavior is similar to their domestic trajectory[9], although for fossil fuels the level is substantially higher than domestic consumption (the energy embodied in imported goods is thus very high). Note also that the increase in fossil fuel consumption goes with a strong decrease in coal extraction from the early 1960s (oil become dominant in the energy mix around 1963).

Metal MF shows important oscillations during Fordism (due to a change in the statistical territory and estimation issues) but still remains below DMC. It then always exceeds DMC for the neoliberal period (from 1976). This category perfectly illustrates the need of the consumption-based approach: MF never stops rising whereas the DMC curve decreases (domestic metal extraction strongly decreases in the 1970s). Taking waste from metal processing abroad into account, there is no dematerialization concerning this category in France (metal footprint exhibits a con-

[9]The use of metal ores and fossil fuels is usually well explained by the GDP per capita (Wiedmann et al., 2015, Table 1).

stant rise since 1965). The transition in accumulation regimes nearly coincides with the shift from net exporter to net importer of metal (in 1978) and with the crossing of the two curves. Table 2 also underlines the specificity of this category: all materials but metal indicate a relative decoupling trajectory during Neoliberalism.

Non-metal MF — the most important category in weight — is close to non-metal DMC. Indeed, these materials are abundant and their extraction unit cost is low. Transportation costs are therefore relatively high in comparison and trade flows are limited[10]. Due to their properties and to political and ecological issues, some flows are thus more concerned by globalization than others. Offshoring of metallic goods and substitution of imported oil for domestic coal is possible but offshoring of construction materials — which compose much of non-metals — is more complicated. Stabilization of both curves can be understood as a saturation of accumulated material stocks (buildings, roads, etc.). Global in-use stocks of manufactured capital already require about half of global material flows for their expansion and maintenance (Krausmann et al., 2017; Wiedenhofer et al., 2015). There is thus an unavoidable material path dependency between socio-metabolic regimes induced by in-use material stocks (Pauliuk and Müller, 2014; Wiedenhofer et al., 2019). Interestingly, the material infrastructure of Neoliberalism rests on, and extends, that of Fordism.

Moreover, not only can the shift from a socio-metabolic regime to another be detected in the dynamics of a series itself but it can also be in the growing difference between DMC and MF series. In that regard, we can see a socio-metabolic shift even for categories whose series exhibit a continuity in their own dynamics, e.g. biomass and metal[11]. In a nutshell, the overall correspondence between socio-metabolic and accumulation regimes is remarkable even if unsurprising and was yet to be investigated in details for France.

Figures 1 and 2 and table 2 indicate that Fordism is an extensive socio-metabolic regime at both domestic and footprint levels. It is characterized by a high annual average growth of material consumption and a low degrowth of domestic material intensity and low growth of the adjusted material intensity. Neoliberalism is an intensive socio-metabolic regime at the domestic level with an annual average degrowth of material consumption and a significant annual average degrowth of material intensity. At the footprint level, it is rather a weakly extensive regime with a low average annual growth of material footprint and a significant average annual degrowth of the adjuted material intensity, albeit lower than at the domestic level. These results are consistent with the characterization of Fordism and Neoliberalism in terms of their social relation to energy as shown by Cahen-Fourot and Durand (2016).

[10] According to the data from Magalhães et al. (2019), non-metallic minerals consist of less than 20% of France's trade flows and concern mainly Germany and Belgium.

[11] In statistical terms, it is unsure whether a structural break analysis would yield any significant result for, e.g., biomass footprint. However, a structural break would probably be detected in the cointegration relationship between biomass DMC and MF, with cointegration turning insignificant after the late 1960s due to a non-trend stationary difference between biomass DMC and MF.

Material consumption	**1948-1973**	**1974-2015**	**Material intensity**	**1950-1973**	**1974-2015**
DMC	*4.2%*	*-0.4%*	*MI*	*-0.8%*	*-2.2%*
Biomass_dmc	1.3%	0.2%	Biomass_mi	-3.5%	-1.6%
Metal_dmc	3.9%	-1.9%	Metal_mi	-0.8%	-3.6%
Non-metal_dmc	8.7%	-0.4%	Non-metal_mi	2.8%	-2.1%
Fossil_dmc	4.2%	-1.0%	Fossil_mi	-0.6%	-2.7%
MF	*5.3%*	*0.1%*	*AMI*	*0.4%*	*-1.7%*
Biomass_foot	3.0%	0.6%	Biomass_ami	-2.5%	-1.2%
Metal_foot	2.7%	1.9%	Metal_ami	11.6%	0.1%
Non-metal_foot	8.3%	0.2%	Non-metal_ami	2.7%	-1.5%
Fossil_foot	5.9%	-0.7%	Fossil_ami	1.6%	-2.5%

Table 2: Annual average growth rate of material consumption and of material intensity of gross value added during Fordism and Neoliberalism. Source: authors calculations from Magalhães et al. (2019) data.

2.4 A growing offshoring of material use

The diverging trajectories of DMC and MF offer a material perspective on the internationalization of French capitalism. Examining the physical and the raw material trade balances (PTB and RTB; presented as imports − exports) substantiates this perspective. As explained before, PTB is the physical equivalent of the monetary trade balance, whereas RTB includes both direct and indirect flows (i.e. it includes also all materials that are not directly composing net imports but were necessary to their production).

Figure 4 shows the evolution of the total and non-fossil fuels (non-FF) PTB since 1948. We see the huge importance of fossil fuels-related materials in France's net imports as France is a net importer in physical terms on the entire period when fossils are considered. The deepening integration of the French economy in the global economy is perhaps better captured if only non-fossil fuel materials are considered: We observe a continuous rise in net imports from the early 1970s onwards. France becomes a net importer in 1994.

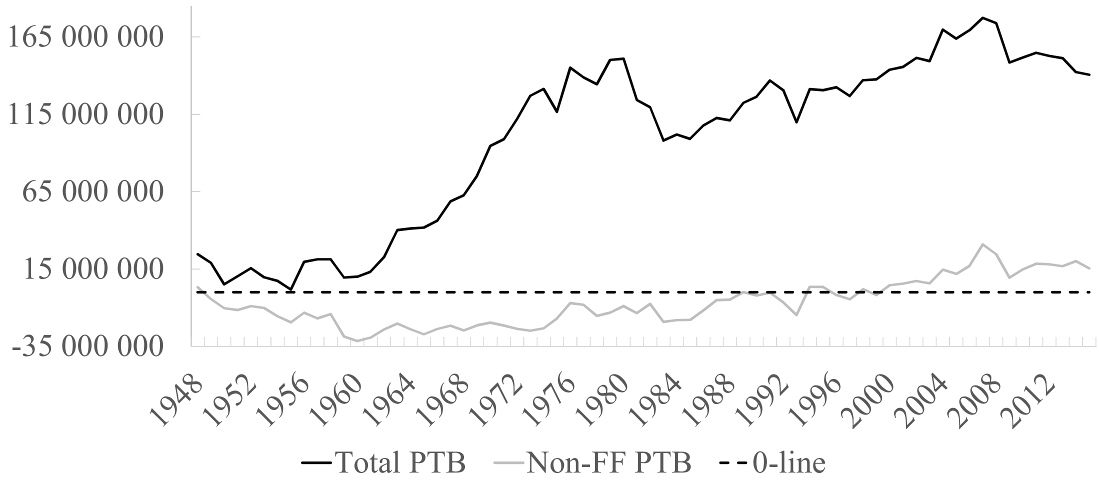

Figure 4: PTB and non-fossil fuels (non-FF) PTB of France from 1948 to 2015, presented as net imports, in tonnes of materials. Source: Magalhães et al. (2019).

RTB (figure 5) corroborates this observation as net imports exhibit a continuous rise since the early 1960s when fossil fuels are included and since the late 1960s when only non-fossil fuels materials are considered. Similarly, after a decade of roughly balanced trade (total RTB) and excess trade (non-FF RTB), France becomes net importer of materials respectively in the early 1960s and late 1970s.

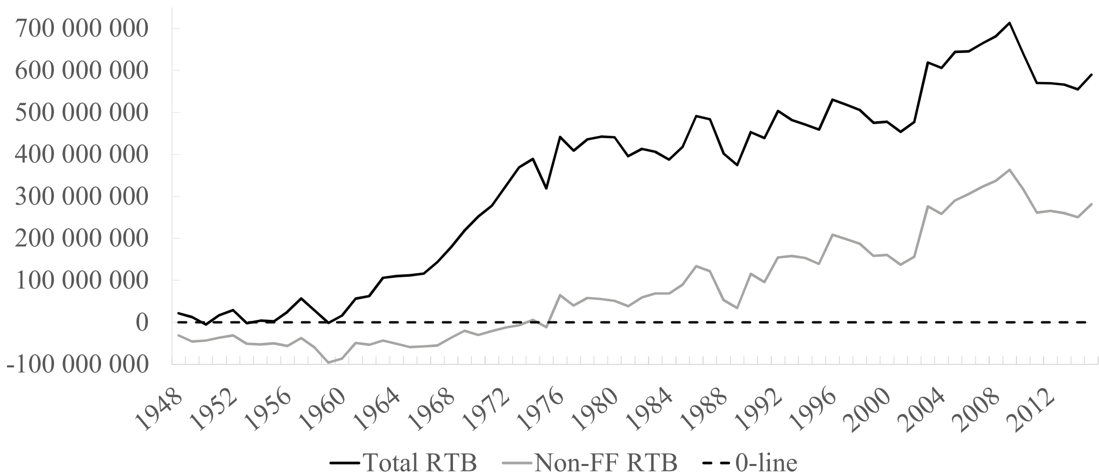

Figure 5: RTB and non-FF RTB of France from 1948 to 2015, in tonnes of materials, presented as net imports. RTB includes both direct and indirect material flows embodied in trade. Source: Magalhães et al. (2019) and authors calculations.

The difference between RTB and PTB is an indicator of the dependency of French capitalism on indirect material flows from trade. Figure 6 presents the rising divergence between RTB and PTB (by construction equal to MF − DMC). After a fast increase in the end of Fordism (1963–1974), the curve slowly and steadily increases, reaching a peak in 2009.

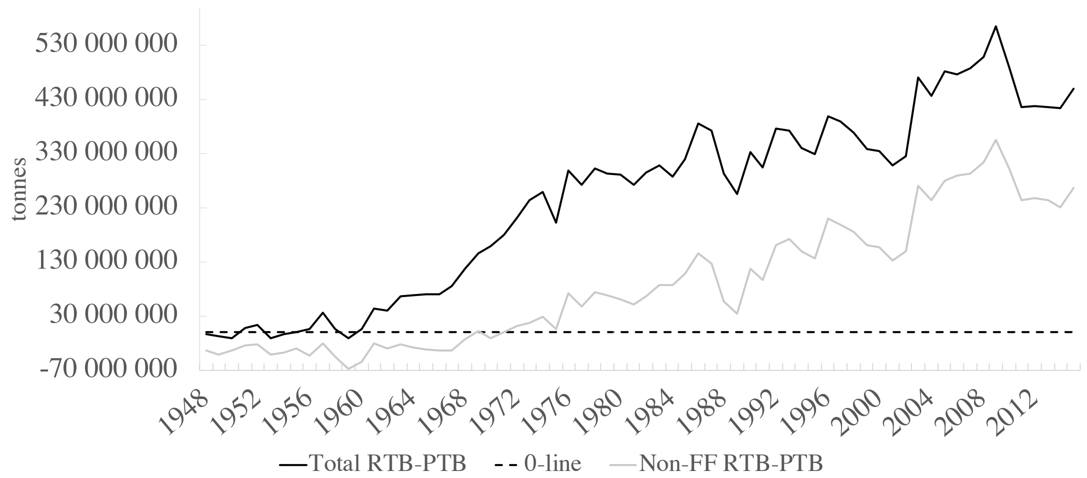

Figure 6: Total and non-FF indirect material flows due to trade ($RTB - PTB = MF - DMC$) at the aggregate level. Source: Magalhães et al. (2019) and authors calculations.

Figure 7 further shows the constantly rising dependency of French capitalism to the global economy as measured through the ratio of DMC and MF to DE, indicating how much of material use is covered by domestic extraction: the MF/DE ratio reached nearly 2 in the last decade, whereas the DMC/DE ratio does not exceed 1.3. In the 2010s, half of the total physical basis of French capitalism came from abroad. This is more than many industrialized countries but still less than high income countries with limited resources such as Netherlands or Switzerland (Bruckner et al., 2012).

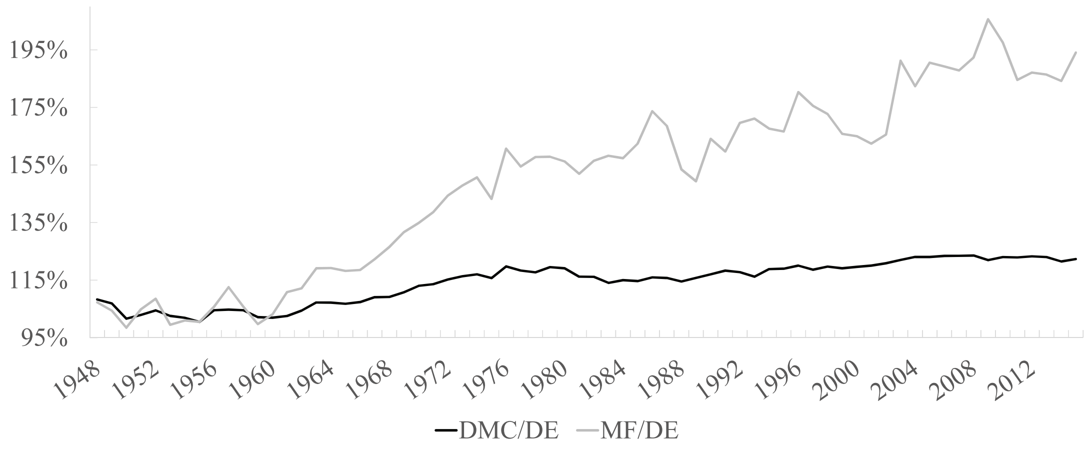

Figure 7: Domestic material consumption to domestic extraction and material footprint to domestic extraction ratios.

We can conclude that the fordist and neoliberal socio-metabolic regimes are of an extensive nature beyond the domestic scale. The dynamics of PTB and RTB indicate that methodological nationalism offers a limited perspective to assert the socio-metabolic regime of a country. In the historical context of globalization, the footprint approach using consumption-based time series brings relevant insights.

3 From Fordism to Neoliberalism: the offshoring-financialization nexus of French capitalism

This section integrates the offshoring of material use to regulationnist explanations of the end of Fordism. Interestingly, the transition from Fordism to Neoliberalism is clearer in physical than in monetary terms. We further provide stylized facts characterizing the financialization of French capitalism. We argue that this process combined with offshoring has reinforced and consolidated the physical dependency of French capitalism to the rest of the world. We therefore illustrate how RT and MFA combine with each other: The growing offshoring of material use highlights a deeper internationalization of French capitalism and the crisis of Fordism. The financialization of French capitalism and its systemic complementarity with the offshoring process can explain the continuous growth of trade flows.

Figure 8 shows the contrast between the material and monetary perspectives. Whereas the monetary trade balance oscillated during Fordism, material imports increased rapidly. From the end of Fordism until 2000, France imported huge quantities of material while in monetary terms exports were greater than imports[12]. France's monetary trade balance — which had been in large surplus until 1976 for common consumer goods — turned to deficit from 2000, especially

[12]This is a typical case of ecologically unequal exchange with the rest of the world (Hornborg, 2012).

for intermediate goods (automotive, electronics, transport equipment etc.), which had hitherto driven exports. From 2003, the trade balance became structurally negative following increasing imports of intermediate and consumer goods and of energy products whose prices literally soared from 2002 to 2007.

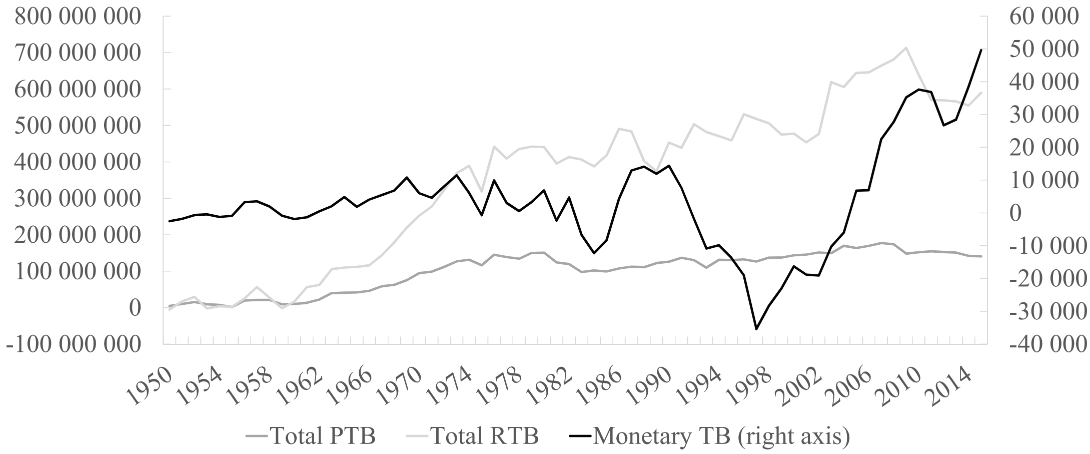

Figure 8: PTB and RTB as net imports are in tonnes (left axis), the monetary trade balance is expressed as net imports in millions of 2010 euro (right axis). Sources: authors' computations and OECDStat.

Increasing imports of intermediate goods are an indication of offshoring (Feenstra and Hanson, 1999; Feenstra and Jensen, 2012). Figure 9 shows the long run offshoring dynamics of French capitalism since 1970 through the share of imported intermediate consumption in total intermediate use of domestic industries. We complement this indicator with the share of imported products in total final demand.

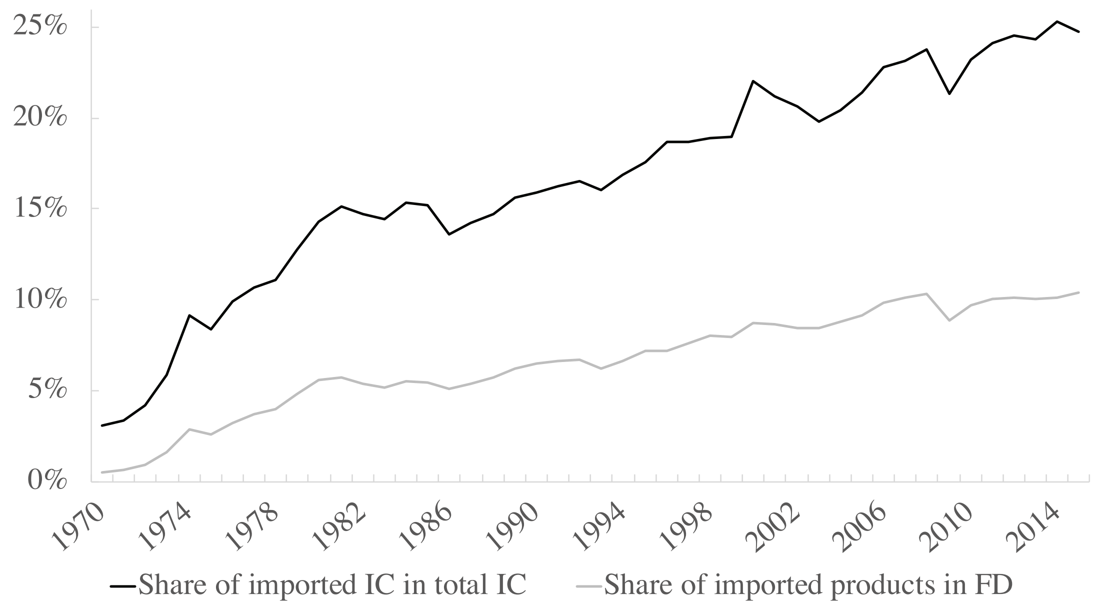

Figure 9: Share of imported intermediate consumption (IC) in total intermediate consumption and share of imported products in final demand (FD). Source: authors' computations with data from Eora 199.82 Input-Output database. Shares with data at basic prices are exhibited but results with data at purchaser prices indicated very similar trends and shares of the same magnitude (slightly lower).

The increasing internationalization of French capitalism as illustrated on figures 4-9 is identified by RT as one of the main cause of Fordism's crisis from the mid-1970s. After infrastructures and capital stocks in key sectors were reconstituted, the domestic market alone became insufficient to support high returns to scale, as shown by slowing productivity gains from the mid-1960s/early-1970s onwards. Exports then appeared as a mean to sustain the accumulation regime based on increasing returns. The average annual growth rate between 1960 and 1968 is 11% for imports and 7.8% for exports (Balladur, 1972, p. 13). Therefore, internationalization in the 1960s initially opened up new growth opportunities and exports complemented domestic wages in the composition of effective demand steering the accumulation regime. However, the increasing importance of exports relatively to wages for steering growth turned price-competitiveness into a major concern of exporting firms (Boyer, 2015; Loiseau et al., 1977; Vidal, 2003). Guillaumet (2002) finds that, between 1850 and 2000, trade had a positive effect on growth only between 1957 and 1974. The productivity gains-wages increases-domestic mass consumption loop underlying the fordist social compromise was then broken and domestic wages became an adjustment variable. All the more so after the collapse of Bretton Woods and the emergence of the European monetary integration from 1972 onwards, with gradual constraints on exchange rates.

Alongside the rise of international trade, finance-led capitalism started to emerge through liberalization of international financial flows and the financialization of high income capitalisms.

French capitalism experienced concomitant internationalization — first through the growing importance of trade, then through the offshoring of production and integration into global value chains — and deep transformation in its financial structure (Morin, 2000).

The systemic complementarity between financialization and offshoring has thus been instrumental in producing a new accumulation regime, together with the emergence of a new mode of regulation that involves deep transformations in the wage-labour nexus[13]. The growth of the invisible trade flows from the 1970s (figures 4-7) is a consequence of this macroeconomic process. The evolution of the distribution of GVA of non-financial corporations in France substantiates this comprehension. We approach financialization through the evolution of the wage and the profit shares in GVA and through financial accumulation.

We look at the non-financial corporations (NFCs). Indeed, we assume NFCs to be the main users of materials through intermediate consumption (between 1950 and 2015, the share of NFCs in total intermediate consumption in monetary terms oscillates between 74 and 83 %, with an increasing trend since 1997[14]). Four stylized facts characterize the financialization of French NFCs as shown on figure 10.

[13] This institutional form began shifting towards capital in labour-capital relations. The other key institutional forms of RT's framework include: the monetary regime, the forms of competition, the form of the state, and the insertion into the international regime. Needless to say, they also underwent transformations in the shift from Fordism to Neoliberalism. A sixth one is currently being discussed: the social relation to the environment Cahen-Fourot (2020).

[14] Authors' calculations from OECDStat national accounting data.

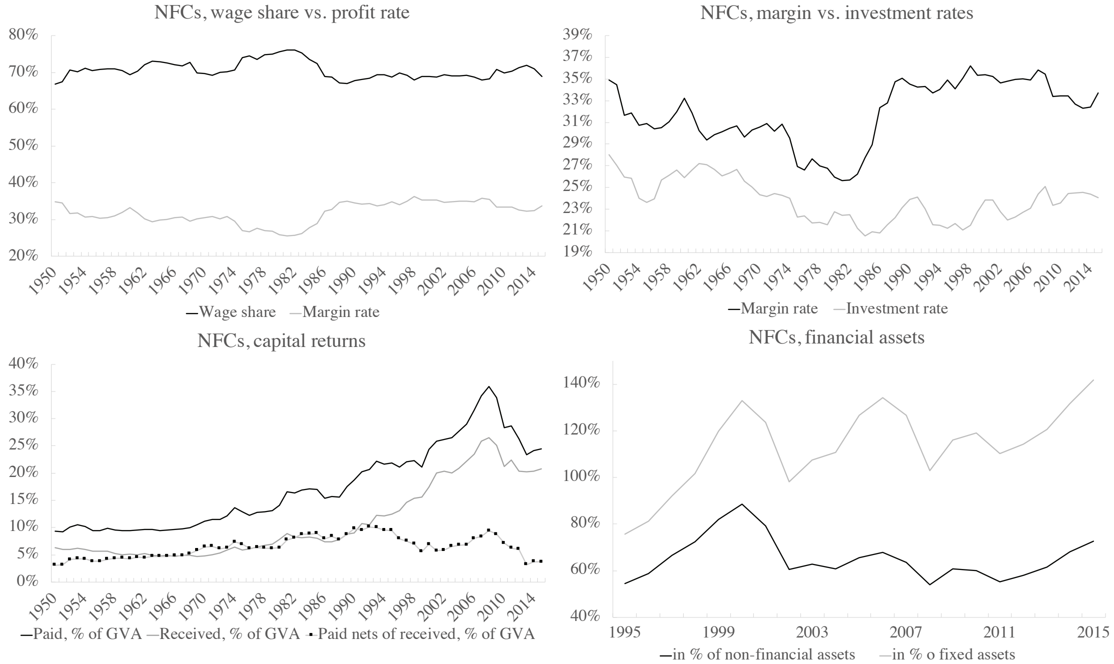

Figure 10: Wage share (compensation of employees / GVA), margin rate (gross operating surplus / GVA), investment rate (GFCF / GVA), capital returns and financial assets of non-financial corporations, 1950-2015. Capital returns paid and received are the sum of, respectively, paid and received distributed income of corporation (mainly dividends) and interests. Source: Authors' calculations from OECDStat data.

The wage share exhibited a slow increase during most of Fordism then increased more in late Fordism and decreased after the oil shocks period, stabilizing during Neoliberalism at a level lower than during Fordism. Symmetrically, the margin rate experienced a decrease from 1950 to the early 1980s, followed by an increase afterwards until the end of the 1980s, then stabilizing at the early Fordism level. The strongest increase in the margin rate is observed at the onset of neoliberal capitalism. What was lost in profit share during Fordism is regained in less than ten years.

Second, we observe a decoupling of the margin and gross fixed capital formation rates. From 1980 onwards, the close correlation between the two series is broken and they increasingly diverge. The investment rate oscillates at a level appreciably lower than during the core of the fordist era and does not follow the increase in the profit share. In line with most studies of financialization, this indicates that the increase in the profit share does not fuel investment in productive capital domestically.

Third, an increasing share of GVA went back to financial capital, in the form of interests and dividends (added together as capital returns on figure 10), which form the distributed profit[15].

[15] This trend would be even stronger if stocks buybacks, a major feature of the shareholder value maximization orientation (Auvray and Rabinovich, 2019), were taken into account.

Capital returns paid continuously increased from the late 1960s to 2008, followed by capital returns received. After the early 1990s, the capital returns paid net of capital returns received decrease as NFCs' financial income gets closer to their distributed profit. This highlight the importance of considering gross as much as net flows. It should not be interpreted as a process of decreasing financialization but rather as another dimension of financialization: Financial income becomes increasingly important for NFCs, which behave more and more like financial investors rather than as producers. This increasing trend exemplifies the shift in corporate strategies from "*retain and reinvest*" to "*downsize and distribute*" corporate governance (Lazonick and O'Sullivan, 2000).

Fourth, this observation is further substantiated by the accumulation of financial assets, whose proportion as compared to fixed assets exhibited a rising trend with important fluctuations during the internet bubble and the subprimes crises. This process of financial accumulation is a well-known stylized fact in the literature on financialization (Krippner, 2005; Stockhammer, 2004). Unfortunately, the data on financial assets are only available from 1995 onwards, which limit our historical hindsight. The data nonetheless indicates an increasing financial capital accumulation as compared to productive capital accumulation. Kovacic et al. (2018) refer to this as an increasing financial intensity when looking at the *financial assets / value added* ratio[16]. Of course, financial assets prices tend to inflate while non-financial assets can depreciate, especially fixed assets (e.g. productive capital). The evolution of these latter ratios can then be partly attributed to the appreciation of financial assets prices. This still shows a financial accumulation in the form of capital gains. Interestingly, however, the evolution is much less clear when non-produced non-financial assets are also considered.

Financialization is deeply linked to the reorganization of production along global value chains and to the restructuring of production in high income countries (Ivanova, 2019). The decrease in production costs enabled by globalization allowed parent firms controlling global value chains to maintain or increase margin rates in a context of price stagnation in their domestic markets. Conversely, shareholders seeking short term returns and managers incentivized by non-wage income like stock-options led firms to enter into active cost-reduction strategies, especially through spread production along global value chains. Conflictuality in capital-labor relations increased: Capital owners and managers gained new avenues for leverage over weakening labor unions and workers taking part in a global labour market (Freeman, 2007) with uneven environmental, wage and labor standards. Together with the decline of industry and the rise of unemployment in their home countries, costs-reduction strategies led to a reduced need for reinvesting profits. They were available for financial accumulation and shareholder value maximization through dividends and stock buybacks. The offshoring-financialization nexus can therefore be comprehended together as forming a successful attempt at restoring the profit share after the fordist era of increasing wages and intensive productive investment in high income countries (Auvray and Rabinovich,

[16]We prefer to look at the financial assets relatively to non-financial and fixed assets as it is a comparison between stocks rather than between a stock — the financial assets at time t and a flow — the value added at time t.

2019; Durand and Miroudot, 2015; Fiebiger, 2016; Ivanova, 2019; Milberg, 2008; Milberg and Winkler, 2010).

4 The dialectics between socio-metabolic and accumulation regimes: a tentative discussion

These observations remain descriptive and shed little light on the causal mechanisms linking socio-metabolic and accumulation regimes. RT prioritized endogenous factors that initially ensured Fordism's success in its analysis of the crisis (Lordon, 2002). Therefore, RT did not integrate material flows for they were considered exogenous factors, e.g. oil[17]. This epistemological stance entailed blindness to the role of materials in supporting accumulation regimes and in shaping institutional compromises of the mode of regulation.

In what follows, we attempt at contributing to remedy this incompleteness. We discuss how cheap and abundant oil allowed for the high productivity gains and mass consumption norms at the basis of the fordist social compromise and how materials may be instrumental in shaping modes of regulation.

4.1 Power of matter: The economic role of materials in underlying accumulation regimes

As we recalled in section 3, productivity gains were the cornerstone of the fordist social compromise through supporting a "virtuous circle" of mass production, mass consumption and high growth accompanied by wage increases, long term employment relations and strong redistribution mechanisms. The high productivity gains of the fordist era did not come out of the blue: Cheap and abundant oil was key in enabling them (Cahen-Fourot and Durand, 2016). This is in particular true for agriculture and industry.

Agriculture experienced the most dramatic changes during Fordism. In 1945, more than 7.5 million people — over a third of the working population — worked in this sector and the country had difficulty feeding the population (ration stamps were maintained until 1949). Successive governments encouraged a strong recovery in production, which required an improvement in productivity. This was possible through cheap oil imports that allowed for strong mechanization and massive use of fossil-based inputs, e.g. fertilizers. As a consequence, from 1950 to 1974, the agricultural population decreased from 29% to 10% of the total working population (Allaire, 1988). Agriculture lost an average of 135 000 jobs per year between 1944 and 1973.

Intensification of agriculture and the increase in biomass production enabled by oil were key in the internationalization that complemented domestic demand in supporting the fordist social

[17] According to Huber (2013, p. 178), Aglietta had recognized the significance of energy to the emerging US fordist mode of mass production in his book of 1979: "*A condition of its success was a revolution in energy which generalized the industrial use of electricity and made possible the construction of high capacity motors which enormously increased the power available to industry.*"

compromise until the beginning of the 1970s. Agricultural exports enabled the trade balance to be in equilibrium between 1960 and 1968 together with the automotive industry. In the late 1960s, exports growth was mainly due to exceptionally high exports of agricultural products while growth in exports of industrial products had slowed down (Balladur, 1972; de Ravignan, 1980). The orientation of agriculture towards exports and its specialization steered high productivity gains that freed up labour absorbed by the industrial sector. Material intensive industries, e.g. mining, metallurgy and the automotive industry, applying taylorist techniques, steered high productivity gains in the manufacturing sector that formed the backbone of the fordist social compromise. Automotive industry's exports were largely in surplus and amounted for most of the trade surplus for the period 1959-1973 (Mistral, 1975).

Nonetheless, mass production alone is not sufficient to stabilize an accumulation regime. A key feature of an accumulation regime is the correspondence between production and the social demand. Mass production had mass consumption as a counterpart, which allowed for the "virtuous circle" of Fordism. Fordist mass consumption norms were also shaped by fossil fuels. The centrality of oil to postwar mass consumption was both direct and indirect. Not only was it the material basis entering countless products (e.g. plastics, clothing, medicine). Its centrality as transportation fuel ensured that even if products were not made with petroleum products, they were distributed and consumed via petroleum-based modes of mobility (Huber, 2013). Oil was key on both sides — production and consumption —, steering the use and production of other materials, e.g. biomass and metals. Through supporting the advent of mass production and mass consumption, materials were thus instrumental in the increase of living standards and upward social mobility of the fordist era in France, which generated a high level of social consensus (Brand and Wissen, 2013).

The transition to the more intensive neoliberal accumulation and socio-metabolic regime has in no way meant a rupture with the extensive and fossilist fordist regime. This is especially true for the *mode of living*, that is the "*dominant patterns of production, distribution, and consumption that are deeply rooted in the everyday practices of the upper and middle classes of the global North and increasingly in the emerging countries of the global South*" (Brand and Wissen, 2012, p. 548). Rather, the more domestic materiality of French capitalism inherited from Fordism is partly substituted for and partly complemented by the more offshore materiality of the neoliberal accumulation regime. Therefore, in terms of socio-metabolic evolution, it seems more relevant to speak of a metabolic addition than of a metabolic transition between the two regimes[18].

Interestingly, in the US case, high productivity gains created stronger pressures for an equally energy-intensive geography of consumption. The persistence of "*petro-capitalism*" is mainly due to the wider embeddedness of oil-dependent consumption norms (Huber, 2013). This is also valid for France, though without domestic mass production. Financialization, through reinforcing offshoring, is enabling to maintain an "*imperial mode of living*" that is the patterns of production

[18] This is coherent with scholarship in environmental history showing that there was never a global energy transition in history but merely energy additions to the pre-existing energy mix (Bonneuil and Fressoz, 2016). This is also consistent with the *longue durée* socio-metabolic regimes mentioned in footnote 6.

and consumption that disproportionately rely on global labour power, resources and sinks (Brand and Wissen, 2013).

4.2 Matter of power: The political role of materials in shaping modes of regulation

Despite their role in sustaining the fordist social compromise, materials had ambiguous effects on the institutionalized compromises regulating the accumulation regime. To some extent, materials were therefore also instrumental in the shift towards Neoliberalism (Cahen-Fourot and Durand, 2016; Debeir et al., 2013; Huber, 2013; Mitchell, 2011).

Workers' ability to control the production and distribution of key material flows were crucial in the advancement of socio-political rights and in the emergence of welfare states in some western countries. Coal exploitation was highly labour intensive and allowed workers to push their agenda, especially in the UK and France. First, coal extraction required high concentration of workers, which made mass social movements and the emergence of organized labour easier. Second, they had the expertise as they worked autonomously deep underearth. Third, coal was distributed by railroads, which enabled railways workers to block its distribution and hence the source of energy of the economy. In other terms, through the characteristics of its exploitation, coal fostered workers' structural and associational powers. The first results from a strategic location in the supply chain while the second results from the collective organization of workers. These three features of coal exploitation therefore gave bargaining power to workers and proved instrumental in the emergence of the French welfare state (Debeir et al., 2013; Mitchell, 2011; Wright, 2000). The latter was to be at the core of the fordist accumulation regime: without the enactment of collective agreements and social security, mass consumption could not have been deployed as a necessary counterpart to mass production.

Coal mines were nationalized in 1946 (creation of the public establishment *Charbonnages de France*) and coal production was made a national priority (noticeable in the first French *Plans*). Though decreasing, coal still dominated the energy mix until 1963. In 1958, France produced 59 Mt of coal and the country had about 145 000 miners. The transition from coal to oil — from a domestic material to an imported commodity — clearly impacted the fordist regime. The low price of oil implied overproduction of coal in the late 1950s. This resulted in the Jeanneney Plan (1959) that explicitly decided to decrease coal production and to reduce the workforce in this sector by closing several coal mines and investing in new oil refineries. In 1962, only two years after the Plan was launched, coal production declined to 52 Mt and the workforce to 120 000.

The addition of oil to the energy mix and its progressive emergence as the main energy carrier had ambiguous effects on the mode of regulation. In contrast to coal, oil extraction and distribution are not labour intensive and oil was mainly imported. The peculiarities of oil exploitation decreased the energy workers' power to push further socio-political demands. There is thus an oil paradox: While cheap and abundant oil enabled the productivity gains providing the foundations of the fordist social compromise, it shifted the power balance between labour and capital, thus laying the ground for the mutation of the wage-labour nexus that had been at the core of Fordism (Cahen-Fourot and Durand, 2016; Mitchell, 2011).

Beyond coal and oil, material intensive industries also conferred strong structural and associational powers upon workers (Silver, 2003; Tronti, 1977; Wright, 2000). In the 1960s, France ranked fourth among European steel producers with approximately 20 Mt. There were more than 100 000 workers in the steel sector in the Lorraine region alone, whereas there are less than 8000 nowadays (Raggi, 2013). The harmful nature of the work and the high costs of extraction lead to substituting imports to domestic production. The decline began in the 1960s with steel from Lorraine losing attractiveness because of imported minerals exhibiting cheaper cost and higher concentration in iron, up to 50-60%. Globalization made price competitiveness key and signalled the shift in French capitalism internationalization from exports complementing domestic demand to offshoring of heavy industries' production. In the aftermath of Fordism, heavy industries concentrating unionized workers and materials were relocated to a great extent. The end of coal and iron ore mining undoubtedly weakened workers. Together with oil, it paved the way for the transformation of the wage-labour nexus and the challenging of the fordist social compromise that would result in the advent of a new mode of regulation supporting the neoliberal accumulation regime.

As mediating tools in the labour-capital relation, materials are instrumental in shaping institutionalised compromises emerging from social struggles and in enabling transformations in the modes of regulation supporting accumulation regimes. Drawing from Cahen-Fourot and Durand (2016), we suggest that the offshoring-financialization nexus affected the mediating role of materials in the labour-capital relation through triggering the relocation of key material flows abroad. Our hypothesis is that the offshoring-financialization nexus reduced the power of French workers to push their socio-political agenda in decreasing their ability to control the use, production and distribution of key material flows. In a self-reinforcing loop, this loss in structural and associational powers — exemplified by the decrease in the wage share and in the unionization rate, that went from 30% in 1949 to 17-20% between 1960 and 1975 and then to around 11% in 2016[19] — may have in turn affected the ability of workers to oppose the process of financialization and the offshoring of industries[20].

Although this paper does not attempt at properly testing this hypothesis, table 3 gives indications regarding the direction of the relation between the key series we presented. Most notably, the wage share is significantly negatively correlated with several variables highlighting the offshoring-financialization nexus such as capital returns paid and received by NFCs, the shares of imported intermediate consumption in total intermediate consumption and imported goods in final demand and with the non-fossil raw trade balance. Other variables exhibit very high

[19]According to the long time series on unionization from the French ministry of labour, https://dares.travail-emploi.gouv.fr/IMG/xlsx/taux_syndicalisation_2016_5oct2018.xlsx, accessed February 25th, 2020.

[20]Another example of the persistence of deindustrialisation is the textile industry that lost two thirds of its jobs and half of its production in the last twenty years. France now imports massive quantities of shoes and wearings and exports luxury products or high value added commodities. The report is available here: https://www.insee.fr/fr/statistiques/3632345

significant correlations between each other, illustrating the systemic complementarity between financialization and offshoring and their close relation with the relocation of material flows.

Pearson pairwise correlations	Wage share	Capital returns paid	Capital returns received	Imported IC in total IC	Imported goods in final demand	Total RTB	Non-fossil RTB	DMC/DE	MF/DE
Wage share	—	-0.33***	-0.33***	-0.27***	-0.33***		-0.28**		
Capital returns paid	-0.33***	—	0.97***	0.86***	0.90***	0.88***	0.95***	0.82***	0.87***
Capital returns received	-0.33***	0.97***	—	0.89***	0.91***	0.78***	0.94**	0.76***	0.81***
Imported IC in total IC	-0.27***	0.86***	0.89***	—	0.99***	0.85***	0.89***	0.81***	0.86***
Imported goods in final demand	-0.33***	0.90***	0.91***	0.99***	—	0.87***	0.90***	0.83***	0.87***
Total RTB		0.88***	0.78***	0.85***	0.87***	—	0.92***	0.98***	0.98***
Non-fossil RTB	-0.28**	0.95***	0.94**	0.89***	0.90***	0.92***	—	0.85***	0.95***
DMC/DE		0.82***	0.76***	0.81***	0.83***	0.98***	0.85***	—	0.97***
MF/DE		0.87***	0.81***	0.86***	0.87***	0.98***	0.95***	0.97***	—

Table 3: Pearson pairwise correlations between the wage share, capital returns paid and received, imported intermediate consumption in total intermediate consumption, imported goods in final demand, total raw trade balance, non-fossil fuels raw trade balance, DMC to DE and MF to DE ratios. Cells left blank are non-significant correlations. Significance threshold set up at 10% with 1% (***) and 5% (**).

We argue, therefore, that accumulation and socio-metabolic regimes combine with each other and are both the product of a given mode of regulation whose evolution is in turn partly shaped by accumulation and material flows dynamics.

5 Conclusion

This paper aims at bringing together MFA and RT to provide a descriptive picture of French capitalism since 1948 in some of its physical and socio-economic dimensions. We first show that the fordist and neoliberal accumulation regimes translate into socio-metabolic regimes. The fordist accumulation regime is an extensive socio-metabolic regime at both domestic and footprint levels. The neoliberal accumulation regime translates into an intensive socio-metabolic regime at the domestic level and into a weakly extensive one at the footprint level. Moreover, the shift from Fordism to Neoliberalism did not imply a change in the mode of living. The offshore materiality of Neoliberalism partly substituted for and partly complemented the more domestic materiality inherited from Fordism. In socio-metabolic terms, the shift of accumulation regime is thus an metabolic addition rather than a metabolic transition.

Second, we attempt at linking the shift from Fordism to Neoliberalism and the offshoring-financialization nexus with the evolution of the material basis of French capitalism. We discuss tentatively how the offshoring of production and the financialization of French non-financial corporations, the disappearance of coal and the shrinking of heavy industries might have affected the mediating role of materials in the labour-capital relation and the structural and associational powers of workers. Fordism's success was enabled by endogenous socio-economic factors — high productivity gains, domestic mass production and mass consumption, exports complementing domestic demand, strong redistribution mechanisms — that have their counterpart as a socio-metabolic regime in the form of material inputs. Fordism's crisis came through these very same factors, with declining productivity gains combining with rising internationalization eventually turning into the offshoring-financialization nexus while French capitalism became increasingly dependent on imported material inputs.

The paper's contribution is therefore fourfold. It sets back the analysis of socio-metabolic regimes into the dynamics of capital accumulation. It shows — in the case of France — that it is accurate to historicize postwar socio-metabolic regimes in terms of Fordism and Neoliberalism. Building amongst others from energy history scholarship, a third contribution of this paper is to tackle how materials may be instrumental in the institutionalized compromises shaping modes of regulation, in particular the wage-labour nexus. Last but not least, the paper is the first attempt at cross-fertilizing RT and MFA. Environmental and material dynamics can no longer be ignored in the regulationnist framework while MFA — and Ecological Economics more generally — can no longer be largely disconnected from the structural evolutions of capitalism.

Yet, our work is not exempt of methodological and theoretical limits. First, we neglect the waste and emissions part of socio-metabolic regimes. Second, MFA minimizes the importance of nuclear energy[21] because it relies on 'light' non-renewable resources, e.g. uranium (Hecht, 2014). The impact of the growth of nuclear energy on the wage-labour nexus and the transition from Fordism to Neoliberalism is unclear. Third, our estimate of the material footprint will be much improved once input-output tables prior to 1970 become available (Lenzen et al., 2013). Fourth, our hypothesis regarding the combined effects of the offshoring-financialization nexus and of materials on the evolution of institutionalized compromises remain to be thoroughly tested. Fifth, the current paper merely insisted upon the wage-labour nexus but other institutional forms — the monetary regime, the form of the state, the form of competition, the insertion into the international regime and the social relation to the environment — were largely ignored.

As one of the first of its kind, this paper calls for further development and opens up new research avenues. One is to understand the structural capitalist causes leading to building new infrastructures that create material path dependency (Chen and Graedel, 2015; Pauliuk and Müller, 2014; Wiedenhofer et al., 2019). Indeed, the measurement of in-use stocks and the role of infrastructures in accumulation regimes would be a crucial step to deepen the analysis. Another is to combine RT results with the valued added appropriation in global value chains perspective on environmental flows responsibility (Piñero et al., 2019) in a long term study. This would permit to complete our analysis at the sectoral level. In particular, the analysis of the construction sector is key to understand the materiality of Fordism and Neoliberalism. Third, taking into account the spatiality of financialization (French et al., 2011) could shed light on the expansion of the commodity frontier induced by the offshoring-financialization nexus. Fourth,

[21] Nuclear energy allows France to save roughly 100 Mt of imported fossil fuel per year.

introducing the other institutional forms in the analysis would allow for a truly systemic account of the dynamics of capitalism in both its socio-economic and material dimensions.

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Appendix to *Matter and regulation: socio-metabolic and accumulation regimes of French capitalism since 1948*

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1 Estimating the material footprint

We use the recent domestic material flow time series for France from Magalhães et al. (2019). Data and indicators are presented for four main material groups: biomass, fossil energy carriers, metallic ores, and non-metallic minerals. Note that the statistical territory varies once in this period: the now German Sarre region was included in the French national statistics until 1959. This has noticeable consequences since Sarre was quite important concerning metal ores.

Different methods exist to compute the material footprint of a country (Eurostat, 2015; Lutter et al., 2016). Multi-Regional Input Output (MRIO) models permit to study and quantify the dependency of countries regarding imports from other parts of the world (Giljum et al., 2015, 2007). Unfortunately, these data usually do not go back further than 1990. The bottom-up coefficient approach is inappropriate for our macroeconomic scale. Indeed, it is very hard to construct solid coefficients for a large number of especially highly processed products (Lutter et al., 2016), especially for a long period. Moreover, we prefer not to implement a hybrid method (MRIO-coefficient approach) that bears the risk of being too opaque.

While usually material footprints are calculated since 1990 (Wiedmann et al., 2015), the Eora database provides time series since 1970 (Lenzen et al., 2012, 2013). Figure A1 shows the graph built from these data. Since the "gap" in 1997 has no consistent explanation (perhaps the Asian financial crash had an impact but such a deep fall resembles more a statistical error), we deleted this outlier from the series and replaced it by a value obtained through linear interpolation.

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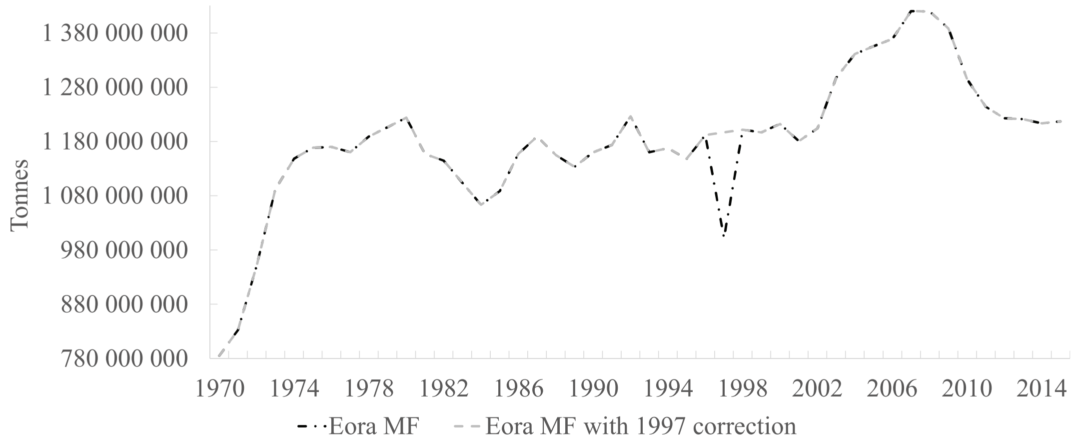

Figure A1: Material footprint from 1970 to 2015 in tonne, with and without the 1997 correction. Source: Data from Eora input-output database (Lenzen et al., 2013).

We then have two series: domestic material consumption (DMC = domestic extraction DE + physical trade balance PTB) since 1948 from Magalhães et al. (2019), and material footprint (MF) from 1970 to 2015 from Eora. To cover the whole 1948-2015 period, we therefore need to estimate MF from 1948 to 1969. It is worth recalling the formula of MF for any year t, for one material category $j \in$*{biomass, metal ores, non-metallic ores, fossil fuels}*:

$$MF_{j,t} = DE_{j,t} + RTB_{j,t} \tag{1}$$

With $RTB_{j,t}$ the raw trade balance (that includes indirect material flows) for the considered material category j. Since $DE_{j,t}$ is known, the key point to approximate the material footprint is therefore to estimate $RTB_{j,t}$. Our assumption is that indirect flows are proportional to trade flows (for each material category): it allows us to approximate the unknown $RTB_{j,t}$ through the known $PTB_{j,t}$. Drawing from this we provide an estimated $\widehat{RTB}_{j,t}$ for each type of material flow.

1.1 Our estimation method

We estimate MF from 1948 to 1975 (see section 1.2 below). The MF values from 1976 onwards for the four main categories come from the Eora database.

For each material category $j \in$*{biomass, metal ores, non-metallic ores, fossil fuels}*, for each year $t \in \{1948, \ldots, 2015\}$, we define

$$\alpha_{j,t} = \frac{RTB_{j,t}}{PTB_{j,t}} \tag{2}$$

This ratio can be computed for 1976-2015: $PTB_{j,t}$ comes from Magalhães et al. (2019) and $RTB_{j,t} = MF_{j,t} - DE_{j,t}$ is deduced from Eora. But we must estimate their unknown values for the 1948-1975 period.

Then, for each j, we compute the median of the vector $(\alpha_{j,1976}, \ldots, \alpha_{j,2015})$. Table 1 provides the values of for all the α over the whole period. The median estimator is suitable here since it is not sensitive to extreme values (it is therefore well-known to be more robust than the mean estimator). Defining the median ratio $\bar{\alpha}_j$ as:

$$\bar{\alpha}_j = median(\alpha_{j,t}, t = 1976, \ldots, 2015) \tag{3}$$

We get $\bar{\alpha}_{biomass} = -3.93$, $\bar{\alpha}_{metal} = 4.68$, $\bar{\alpha}_{non-metal} = 3.85$, $\bar{\alpha}_{fossil} = 2.48$.

We then find, for $t \in \{1948, \ldots, 1975\}$ and for each material category j:

$$\widehat{RTB}_{j,t} = \bar{\alpha}_j PTB_{j,t} \tag{4}$$

and

$$\widehat{MF}_{j,t} = DE_{j,t} + \widehat{RTB}_{j,t} \tag{5}$$

The MF values for 1976-2015 come from Eora.

Category	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Biomass	-9.24	-5.86	-5.85	-4.23	-5.45	-11.58	-20.76	-18.06	-9.88	-7.67	-5.96	-3.99	-4.55	-3.30	-2.09
Metal	3.70	3.19	2.90	2.43	2.21	1.06	-2.58	-20.12	-13.21	10.70	4.44	5.25	5.02	14.61	6.95
Non-metal	-0.94	-1.77	-0.52	0.81	4.85	1.18	10.84	4.71	3.85	4.46	9.90	11.04	6.18	4.88	1.91
Fossil Fuel	0.57	0.88	1.47	2.03	2.32	2.76	2.48	2.51	2.52	2.37	2.44	2.59	2.78	2.88	2.66

Category	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Biomass	-1.85	-3.63	-2.90	-2.12	-2.03	-3.81	-3.38	-2.71	-2.49	-4.27	-4.34	-4.77	-3.07	-3.93	-2.95
Metal	5.71	5.88	4.35	3.32	3.10	3.34	3.77	5.18	5.68	4.07	2.41	5.12	1.16	4.56	4.78
Non-metal	13.34	30.58	0.63	-15.65	-9.37	-20.45	-7.02	0.26	8.14	-1.26	-3.03	1.80	-29.75	-2.47	-4.58
Fossil Fuel	2.80	2.99	3.08	3.02	2.78	2.63	2.50	2.54	2.60	2.49	2.51	2.40	2.19	2.36	2.27

Category	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Biomass	-3.45	-3.79	-4.24	-5.67	-5.67	-5.30	-5.62	-7.24	-7.22	-5.92	-4.12	-3.78	-3.79	-3.31	-2.43	-3.02
Metal	4.23	4.68	3.33	5.46	4.77	5.41	4.80	4.49	4.92	7.94	4.71	4.34	4.83	4.23	3.90	3.75
Non-metal	-4.72	-5.30	-1.19	1.49	2.08	2.80	3.94	4.69	5.28	8.45	5.29	2.89	3.99	3.86	4.63	5.25
Fossil Fuel	2.28	2.26	2.22	2.38	2.24	2.33	2.23	2.33	2.30	2.51	2.35	2.26	2.25	2.27	2.49	2.46

Table 1: Coefficients $\alpha_{j,t}$ for $j \in${*biomass, metal ores, non-metallic ores, fossil fuels*}, for each year $t \in \{1970, \ldots, 2015\}$.

Note that for metals, multiplying the embodied metal in imported goods by 4.68 in 1976-2015 requires to assume that exported commodities in 1948-1975 have the same embodied content. Nevertheless, France was then exporting a lot of iron ore, with less embodied metal than a manufactured good (figure A2). We thus decided to split the metal category into two subcategories: iron ore and others. We then applied the estimated coefficient to the second one only. This choice is not arbitrary: It is well known that iron represents by far the main metal subcategory (Schaffartzik et al., 2016). That was necessary to avoid a negative MF for metals between 1948 and 1975, which made little sense, if at all[1].

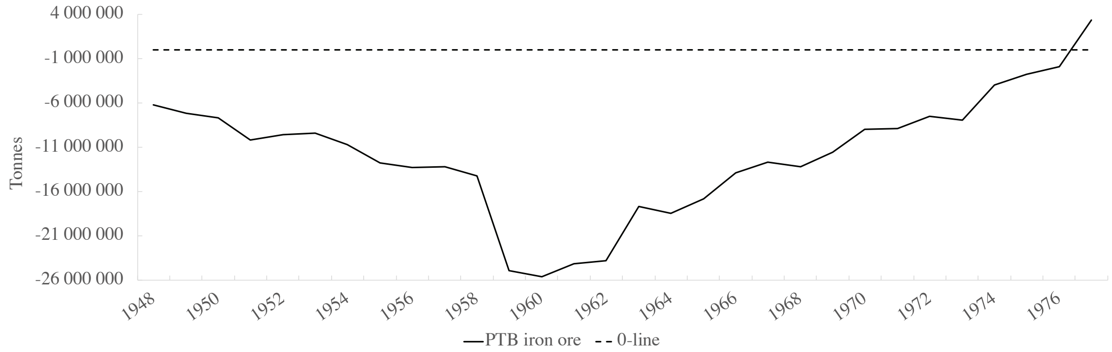

Figure A2: Physical trade balance of iron ore (1948-1977). Data from Magalhães et al. (2019).

Concerning the iron ore trade, we used the coefficient of 1.27 that provides an approximation of the gross ore needed to export one unit of concentrate content (Eurostat, 2018, p. 55). Of course this is only a proxy – since iron content can vary a lot over time and between imports and exports.

As for biomass, Wiedmann et al. (2015) suggest to break it down into two main subcategories to gain additional insights into the use of biomass: i) crops for human consumption and ii) fodder crops, crop residues, and grazed biomass. In the case of the present analysis, this was not needed. Also, our estimate for biomass do not exhibit any strange values or trends.

1.2 Choice of estimation period

An important question concerns the length of the period we want to estimate: Do we use the Eora data for the whole 1970-2015 period or do we split the data and if so, when and why ? Using the same method, we tested all splits from 1970 to 1995 (26 splits). For the 1970s, we get the following table.

[1] A negative material footprint is possible only if a country uses none of its material stock for domestic purpose and exports all or a part of it. It can never happen at a large scale for such a long period, especially a period of post-war reconstruction.

Category	1970	1971	1972	1973	1974	1975	**1976**	1977	1978	1979	1980
Biomass	-4.23	-4.18	-4.12	-4.06	-3.99	-3.96	**-3.93**	-3.87	-3.81	-3.80	-3.79
Metal	4.44	4.46	4.49	4.52	4.56	4.62	**4.68**	4.70	4.71	4.74	4.71
Non-metal	2.80	2.84	2.89	3.37	3.85	3.37	**3.85**	3.37	2.89	2.84	2.80
Fossil	2.44	2.45	2.46	2.47	2.48	2.48	**2.48**	2.48	2.46	2.45	2.46

Table 2: Estimated coefficients. Each column corresponds to a split: the 1976 column provides the coefficients we found with this estimation method. The 1970 column corresponds to the median applied to all coefficients from 1970 onward.

We excluded the first estimates (split in: 1970, 1971, 1972) because the last estimated value of the series was much higher than the following Eora value (figure A3). This strong decrease (in 1970, 1971 or 1972) does not match reality since these years of high GDP growth correspond to a period of important increase in imports and domestic extraction (Magalhães et al., 2019).

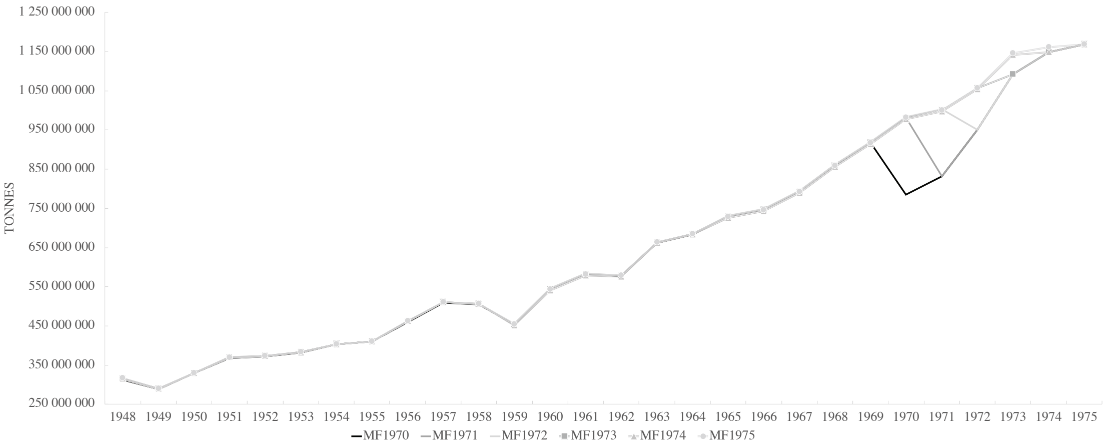

Figure A3: Comparison of material footprint estimates 1970 to 1975.

Therefore, we chose to split in 1975-1976 for a better accuracy of the estimation of the metal category and to use Eora data from 1976 onwards. This allows us to avoid a gap generated by later splits, e.g. splits in the years 1977 to 1980 that created a strong decrease followed by a strong increase in the late 1970 (figure A4). The years 1948-1975 are thus estimated and Eora data are used for the years 1976-2015. Obivously this approach is limited but we consider it accurate enough to estimate the main trends.

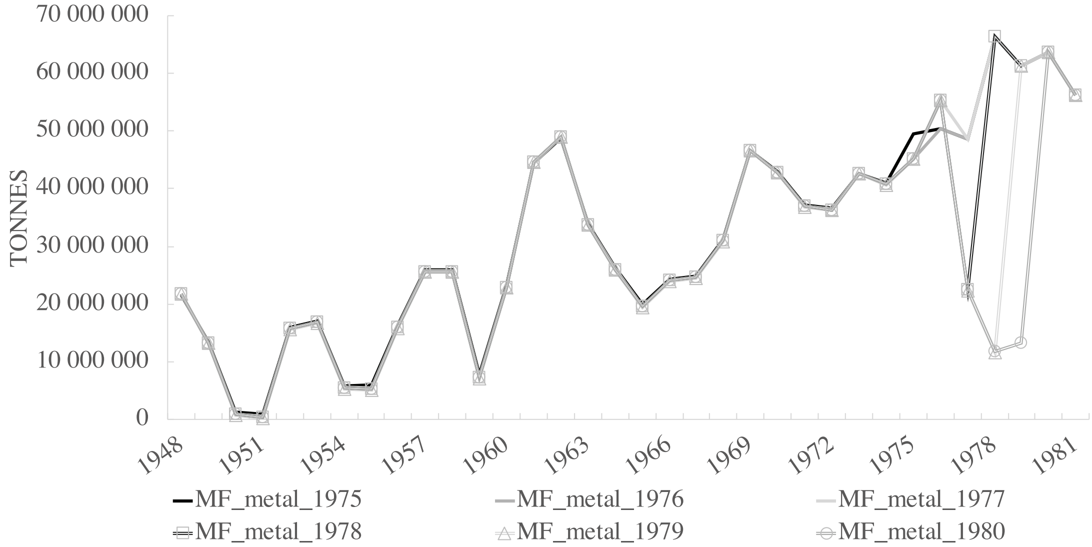

Figure A4: Comparison of MF metal estimates 1975 to 1980.

2 Relative trajectories in terms of GVA: disaggregated materials

When disagreggating the *DMC/GVA* and *MF/GVA* ratios (figure A5), we see that all materials but metal indicate a relative decoupling trajectory. The biomass intensity of gross value added continuously decreases in both domestic and footprint approaches for our time span. Non-metal intensity increases during Fordism and decreases since the onset of Neoliberalism. Domestic fossil fuel intensity decreases since the early 1960s while the footprint fossil fuel intensity has increased during Fordism and decreases since the mid-1970s. As for metal, relative decoupling appears to occur at the domestic level from the early 1960s to the early 1980s with a stabilization of the *metal/GVA* ratio since then. The footprint metal intensity indicates a symmetrical pattern: an increase from the early 1960s to the early 1980s and a stabilization since then. This reveals a strong correlation of footprint metal with the GVA over a long period. This illustrates the relocation of metallurgy, whose share in GVA went from 2.3% of GVA in 1959 to 1.3% of GVA in 2015 according to OECD national accounting data in terms of NACE sectoral activities.

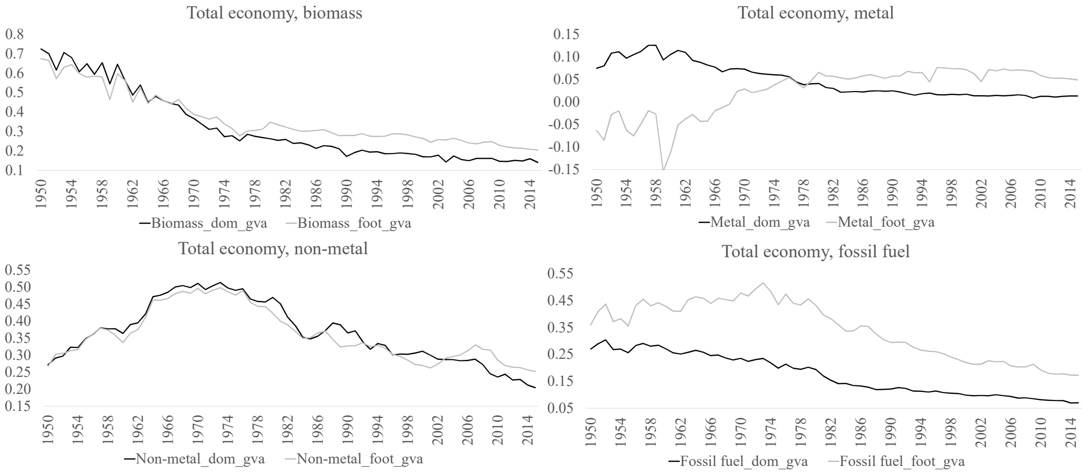

Figure A5: Disaggregated domestic and footprint material intensity of GVA at factors cost in kilo per 2010 euro.

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