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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.

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

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

48 Two distinct accumulation regimes have been identified in the post-war era in France: Fordism,
49 from the early years of post-war recovery to the mid-seventies and Neoliberalism from then on-
50 wards. Fordism can be characterized by high productivity gains supporting a social compromise
51 between labour and capital in favour of labour resulting into strong redistributive institutions
52 such as the welfare-state and social security, long term employment relations and an accumula-
53 tion process led by domestic mass consumption. Neoliberalism is characterized by the progressive
54 dismantling and replacement of the welfare by a market regulator state, the flexibilization of em-
55 ployment relations and liberalization of goods, services and financial flows and the rise of finance
56 as a dominating sector of the economy and of financial motives as the leading principle of non-
57 financial corporate governance (Boyer, 2015; Duménil and Lévy, 2014; Harvey, 2014; Husson,
58 2012; Lazonick and O’Sullivan, 2000).

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

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

74 In the reminder of this paper, we first provide in section 2 a short methodological introduction
75 to MFA. We then present data to characterize the fordist and neoliberal socio-metabolic regimes
76 and to approach the internationalization of French capitalism in a physical perspective. In section
77 3, we draw from this new perspective on internationalization and discuss accumulation regimes
78 and the shift from Fordism to Neoliberalism. In section 4, we investigate possible causalities

79 relating accumulation and socio-metabolic regimes in discussing the role of material in economic
80 and political processes. We conclude by pointing out some limits and perspectives of this work.

81 **2 Fordist and neoliberal socio-metabolic regimes: from an** 82 **extensive domestic to an extensive offshore materiality**

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

89 **2.1 Material flow analysis: a methodological introduction**

90 MFA most often focuses on the domestic scale, for which long term statistics exist (Eurostat,
91 2018). Common indicators are domestic extraction (DE), imports (I), exports (E), physical
92 trade balance ($PTB = I - E$) and the domestic material consumption ($DMC = DE + PTB$).
93 The material intensity (MI) of an economy corresponds to the DMC -to- GDP ratio (see table 1).
94 It is worth recalling that DMC adds flows of a very different nature: domestic extraction refers to
95 raw materials whereas trade flows are a mix of raw and manufactured commodities. Some (low-
96 income) extractive countries have therefore a much higher DMC per capita than high income
97 countries. For instance, this can lead to the (wrong) conclusion that Chile consumes three times
98 more material per capita than France or Germany¹. DMC is generally the main indicator to
99 assess national material dynamics. Many industrialized countries have instituted policies (Giljum
100 et al., 2015; OECD, 2019; Wiedmann et al., 2015) encouraging ‘dematerialization’ by setting
101 decreasing material intensity targets (e.g until recently MI was considered a key indicator of
102 the EU sustainable development and Europe 2020 strategies). However, DMC ’s methodological
103 nationalism entails blindness to indirect material flows generated abroad to satisfy a country’s
104 final demand.

105 Indirect flows are relevant measures of environmental load displacement because they re-
106 main in the exporting country but are necessary for the provision of exports (Dittrich et al.,
107 2012). Since production and consumption in high income countries are increasingly dependent
108 on material and energy resources from other world regions², environmental impacts have been

¹Respectively 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).

²Between 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).

109 increasingly approached through the whole ecological cost — the footprint — of material use
110 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)

$$MF = DE + RTB$$

111 where *RTB* is the *raw trade balance* that is raw material equivalents of imports minus raw
112 material equivalents of exports. It is important to note that the concept of RME refers only
113 to “used materials” — that is, those material flows that enter economic processes. The other
114 component of these indirect flows, so-called unused extraction³, is not included in RME and,
115 despite its ecological relevance, is not considered here. Material inputs included in RME are
116 therefore necessary to produce an output. A certain portion of such inputs, however, is embodied
117 in the final outputs, whereas the rest of the material is dissipated along the production chain or
118 recycled.

119 The difference between DMC and MF can be huge for metal-exporting countries (with MF
120 < DMC) and high income industrialized countries (with MF > DMC; except for Australia).
121 This change is particularly important for Europe, the region with the highest share of materials
122 embodied in imports (Giljum et al., 2015). Bruckner et al. (2012, table 5) show that MF was
123 49% higher than DMC in 2005 for France. A final motivation to adopt a material footprint
124 perspective for France is the steep increase from 15% in 1948 to over 50% in 2015 of the amount
125 of imports compared to domestic extraction (*I/DE*) (Magalhães et al., 2019).

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

³Upstream 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).

138 construction can be found in the appendix⁴. Table 1 sums up the main MFA concepts.

acronym	unit	meaning / definition
DE	t	<i>Domestic Extraction</i>
$PTB = I - E$	t	<i>Physical Trade Balance</i>
$DMC = DE + PTB$	t	<i>Domestic Material Consumption</i>
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	<i>Raw Trade Balance</i>
$MF = DE + RTB$	t	<i>Material Footprint</i> (or <i>Raw Material Consumption</i>)
$MI = DMC/GDP$	t per US\$	<i>Material Intensity</i> : efficiency of material use
$AMI = MF/GDP$	t per US\$	<i>Adjusted Material Intensity</i> : efficiency of material use corrected for MF
$MP = GDP/DMC$	US\$ per t	<i>Material Productivity</i>

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

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

142 2.2 An aggregate material view at French capitalism

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

⁴While 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.

⁵Here 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).

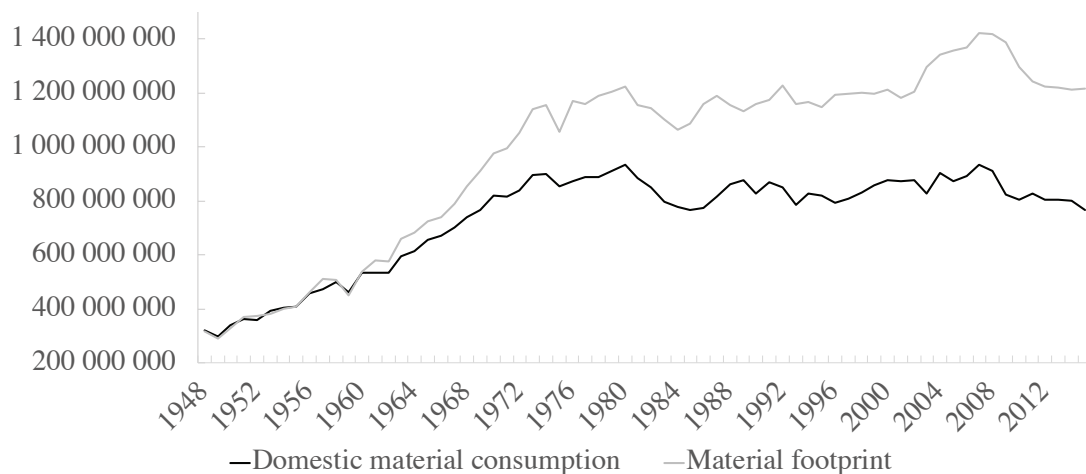


Figure 1: Domestic material consumption and material footprint in tonnes from 1948 to 2015. Sources: Lenzen et al. (2012, 2013); Magalhães et al. (2019) and authors' computations.

146 This figure indicates no dematerialization of French capitalism despite technological improve-
 147 ments and the shift of production toward services. It confirms that accumulation regimes as
 148 identified by RT have their counterpart in terms of socio-metabolic regimes⁶. We observe a clear
 149 break in the 1970s, as already observed by Wiedenhofer et al. (2013) and Cahen-Fourot and
 150 Durand (2016) for energy. The shift between Fordism and Neoliberalism in the 1970s appears as
 151 a stabilization of material consumption at the domestic scale and as an increasing offshoring as
 152 indicated by the footprint trajectory. Moreover, the divergence of the two curves that emerges
 153 in the mid-1960s highlights the importance of the footprint perspective. These curves follow a
 154 very similar path up until the end of the 1960s and shift apart at the onset of the globaliza-
 155 tion era. Both curves exhibit an increasing trend up until the late 1970s. DMC then shows a
 156 fluctuating yet flat trend afterwards, whereas the MF curve keeps increasing (although slower).
 157 All series experience another shift in the years 2007-2009 at the outburst of the global financial
 158 and economic crisis. Trajectories did not then come back to their previous trends as the figure
 159 shows. As of today, it is still unclear whether this is due to evolutions in production processes
 160 and structures or to the ongoing consequences of the crisis⁷. MF grew 4-fold since 1948, from
 161 316 Mt⁸ to 1217 Mt in 2015 (the population then rose from 41.1 to 66.4 million), reaching a peak
 162 of 1420 Mt just before the financial crisis of 2008.

⁶Initially three main socio-metabolic regimes were identified in human history: hunter-gatherers, agricultur-
 alists, 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.

⁷Kovacic 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.

⁸One megatonne (Mt)=10⁶ tonnes (t).

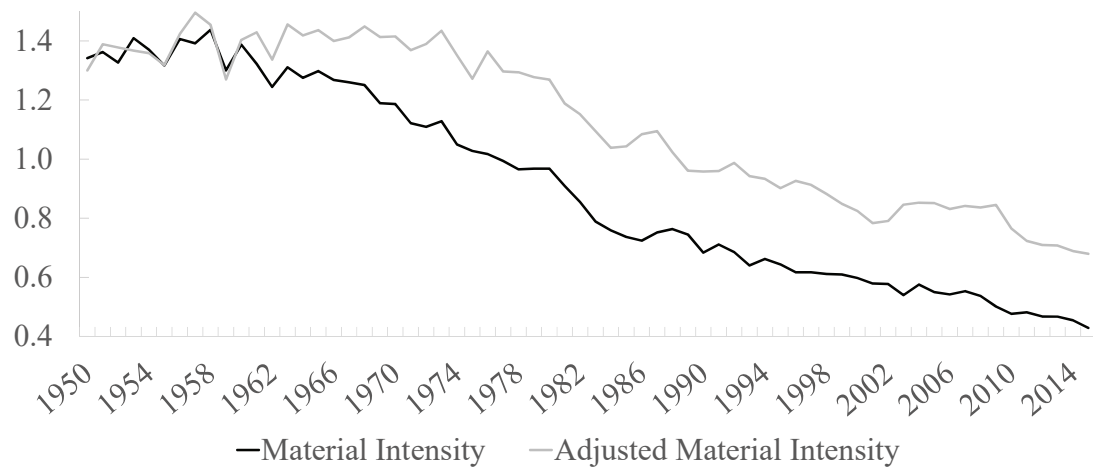


Figure 2: Domestic and footprint adjusted material intensity of GVA at factors cost in kilo per 2010 euro. Sources: authors' computations from Lenzen et al. (2012, 2013); Magalhães et al. (2019) and OECDStat data.

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

167 **2.3 A disaggregate material view at French capitalism**

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

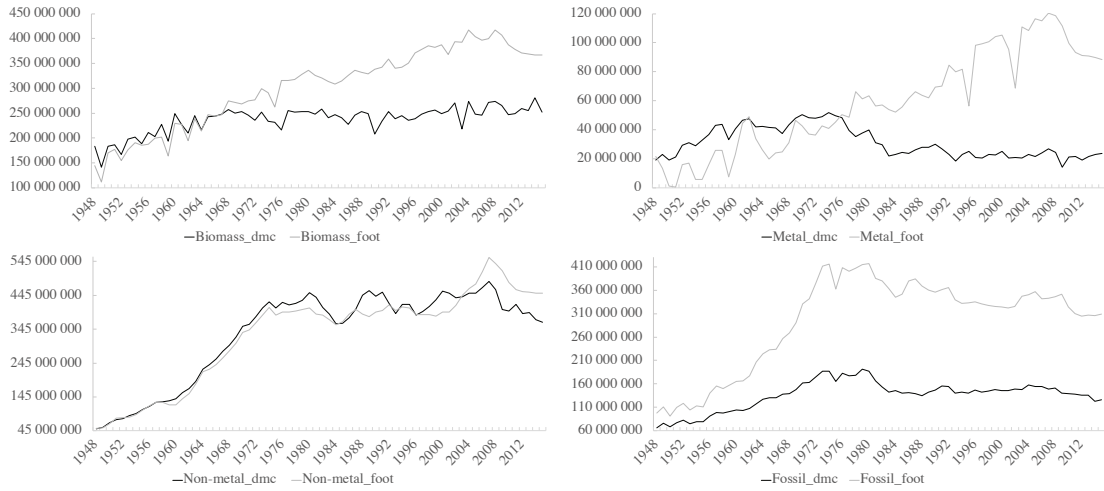


Figure 3: DMC and MF for biomass, metal, non-metal and fossil fuel. All data are in tonnes from 1948 to 2015. Sources: authors' computations from Lenzen et al. (2012, 2013); Magalhães et al. (2019).

171 In the DMC perspective, we observe clear shifting trends for all curves in the mid- and late-
 172 1970s. Biomass continuously increases since 1948 but with a much flatter shape after the twilight
 173 of Fordism in the late 1960s. Non-metallic minerals acknowledge the strongest increase, with an
 174 average annual growth of 8.7% for 25 years (table 2). Metal consumption stops increasing and
 175 experiences a continuous decrease since the end of Fordism while non-metal consumption strongly
 176 oscillates but does not exhibit an increasing trend after Fordism. Fossil fuel consumption reaches
 177 a maximum in 1980, after the second oil crisis, then sharply decreases and remains stable for 20
 178 years. The fossil fuel DMC has decreased further after the 2008 crisis.

179 MF offers a slightly different picture. Biomass and metal continuously increase, respectively
 180 from 1948 and the early 1960s, indicating no shift between Fordism and Neoliberalism. Contrari-
 181 wise, non-metal and fossil fuel footprints indicate again a break in the mid-1970s. Their behavior
 182 is similar to their domestic trajectory⁹, although for fossil fuels the level is substantially higher
 183 than domestic consumption (the energy embodied in imported goods is thus very high). Note
 184 also that the increase in fossil fuel consumption goes with a strong decrease in coal extraction
 185 from the early 1960s (oil become dominant in the energy mix around 1963).

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

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

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

196 Non-metal MF — the most important category in weight — is close to non-metal DMC.
197 Indeed, these materials are abundant and their extraction unit cost is low. Transportation costs
198 are therefore relatively high in comparison and trade flows are limited¹⁰. Due to their properties
199 and to political and ecological issues, some flows are thus more concerned by globalization than
200 others. Offshoring of metallic goods and substitution of imported oil for domestic coal is possible
201 but offshoring of construction materials — which compose much of non-metals — is more
202 complicated. Stabilization of both curves can be understood as a saturation of accumulated
203 material stocks (buildings, roads, etc.). Global in-use stocks of manufactured capital already
204 require about half of global material flows for their expansion and maintenance (Krausmann
205 et al., 2017; Wiedenhofer et al., 2015). There is thus an unavoidable material path dependency
206 between socio-metabolic regimes induced by in-use material stocks (Pauliuk and Müller, 2014;
207 Wiedenhofer et al., 2019). Interestingly, the material infrastructure of Neoliberalism rests on,
208 and extends, that of Fordism.

209 Moreover, not only can the shift from a socio-metabolic regime to another be detected in the
210 dynamics of a series itself but it can also be in the growing difference between DMC and MF
211 series. In that regard, we can see a socio-metabolic shift even for categories whose series exhibit
212 a continuity in their own dynamics, e.g. biomass and metal¹¹. In a nutshell, the overall corre-
213 spondence between socio-metabolic and accumulation regimes is remarkable even if unsurprising
214 and was yet to be investigated in details for France.

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

¹⁰According 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.

¹¹In 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
<i>DMC</i>	4.2%	-0.4%	<i>MI</i>	-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%
<i>MF</i>	5.3%	0.1%	<i>AMI</i>	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.

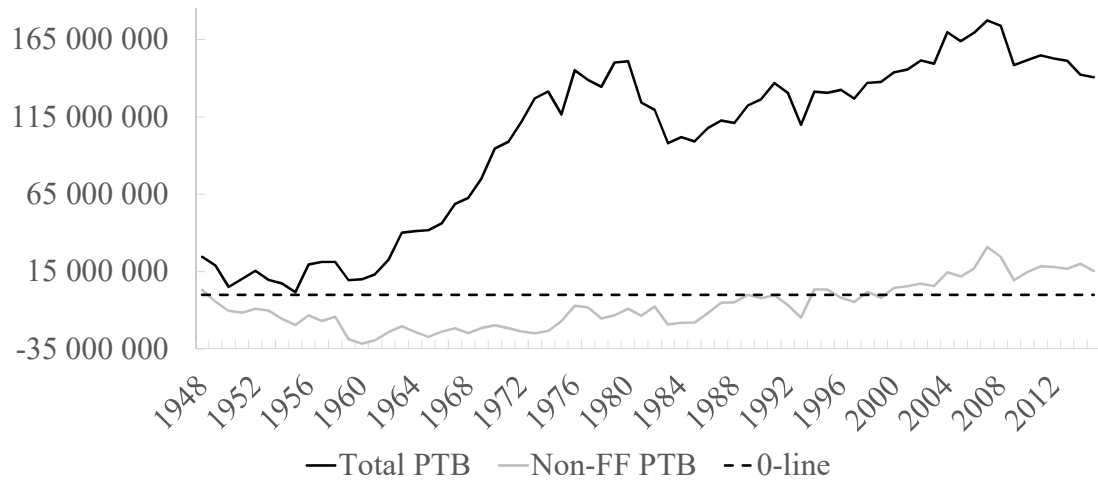


Figure 4: PTB and non-fossil fuels (non-FF) PTB of France from 1948 to 2015, presented as net imports, in tonnes of materials. Source: Magalhães et al. (2019).

238 RTB (figure 5) corroborates this observation as net imports exhibit a continuous rise since
 239 the early 1960s when fossil fuels are included and since the late 1960s when only non-fossil fuels
 240 materials are considered. Similarly, after a decade of roughly balanced trade (total RTB) and
 241 excess trade (non-FF RTB), France becomes net importer of materials respectively in the early
 242 1960s and late 1970s.

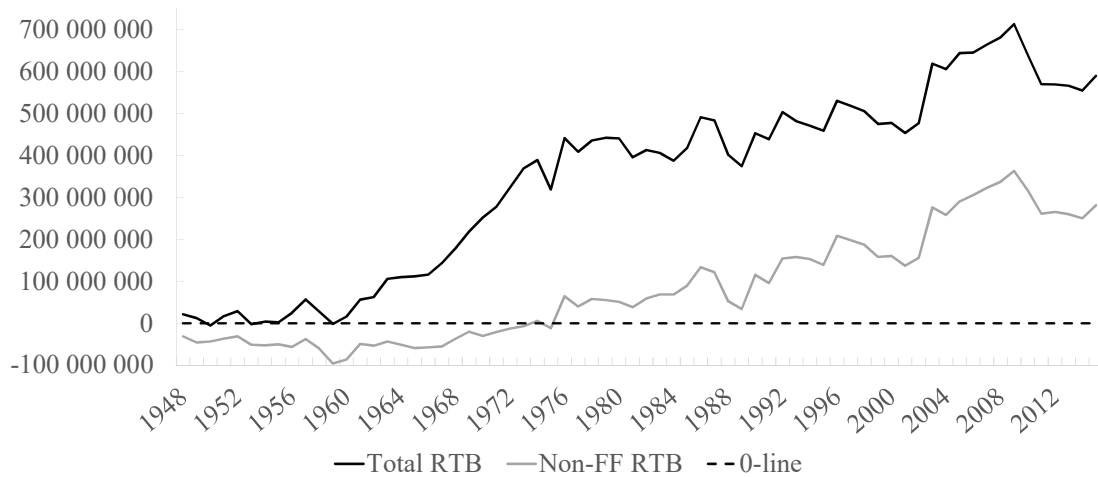


Figure 5: RTB and non-FF RTB of France from 1948 to 2015, in tonnes of materials, presented as net imports. RTB includes both direct and indirect material flows embodied in trade. Source: Magalhães et al. (2019) and authors calculations.

243 The difference between RTB and PTB is an indicator of the dependency of French capitalism
 244 on indirect material flows from trade. Figure 6 presents the rising divergence between RTB

245 and PTB (by construction equal to $MF - DMC$). After a fast increase in the end of Fordism
 246 (1963–1974), the curve slowly and steadily increases, reaching a peak in 2009.

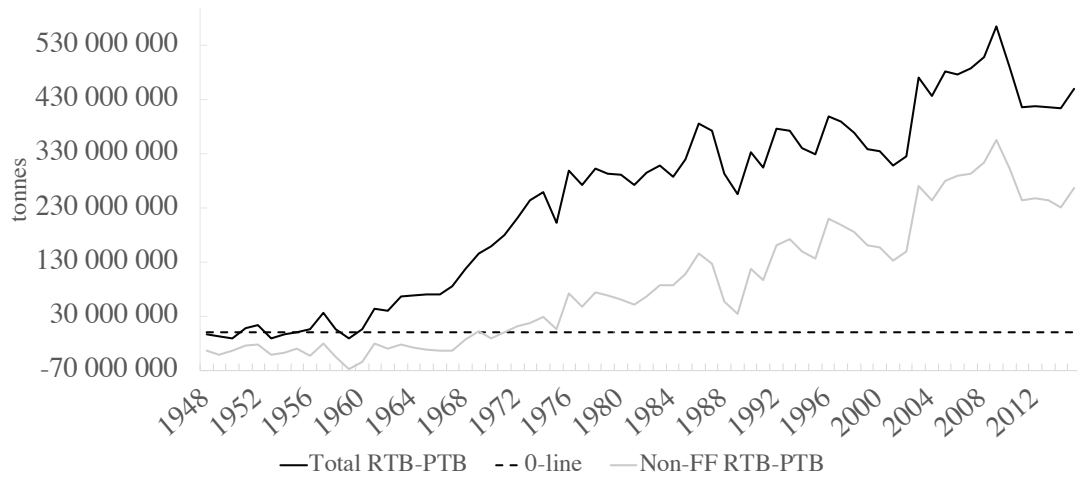


Figure 6: Total and non-FF indirect material flows due to trade ($RTB - PTB = MF - DMC$) at the aggregate level. Source: Magalhães et al. (2019) and authors calculations.

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

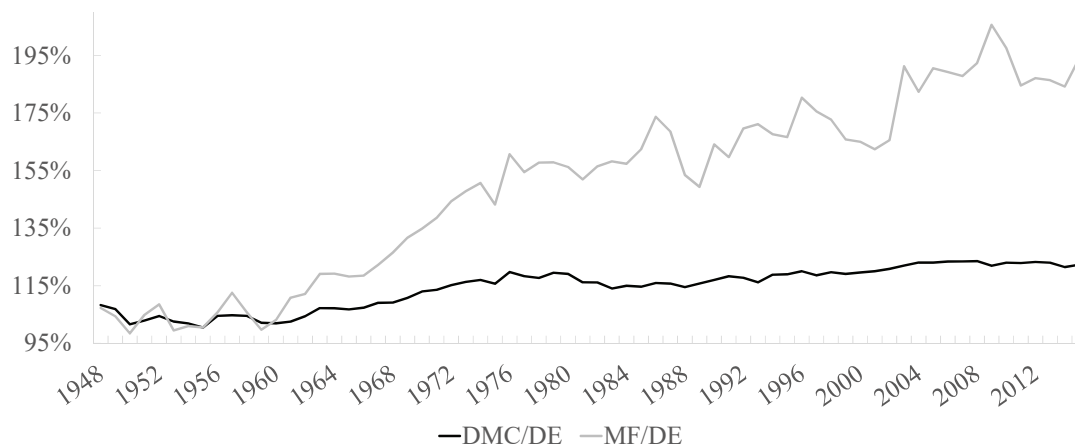


Figure 7: Domestic material consumption to domestic extraction and material footprint to domestic extraction ratios.

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

259 **3 From Fordism to Neoliberalism: the offshoring-financialization** 260 **nexus of French capitalism**

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

270 Figure 8 shows the contrast between the material and monetary perspectives. Whereas the
 271 monetary trade balance oscillated during Fordism, material imports increased rapidly. From the
 272 end of Fordism until 2000, France imported huge quantities of material while in monetary terms
 273 exports were greater than imports¹². France's monetary trade balance — which had been in
 274 large surplus until 1976 for common consumer goods — turned to deficit from 2000, especially

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

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

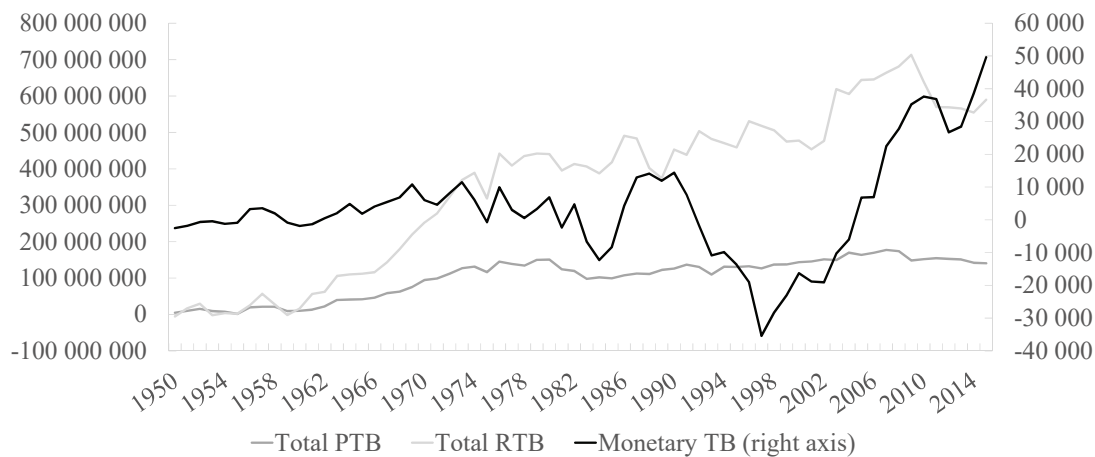


Figure 8: PTB and RTB as net imports are in tonnes (left axis), the monetary trade balance is expressed as net imports in millions of 2010 euro (right axis). Sources: authors' computations and OECDStat.

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

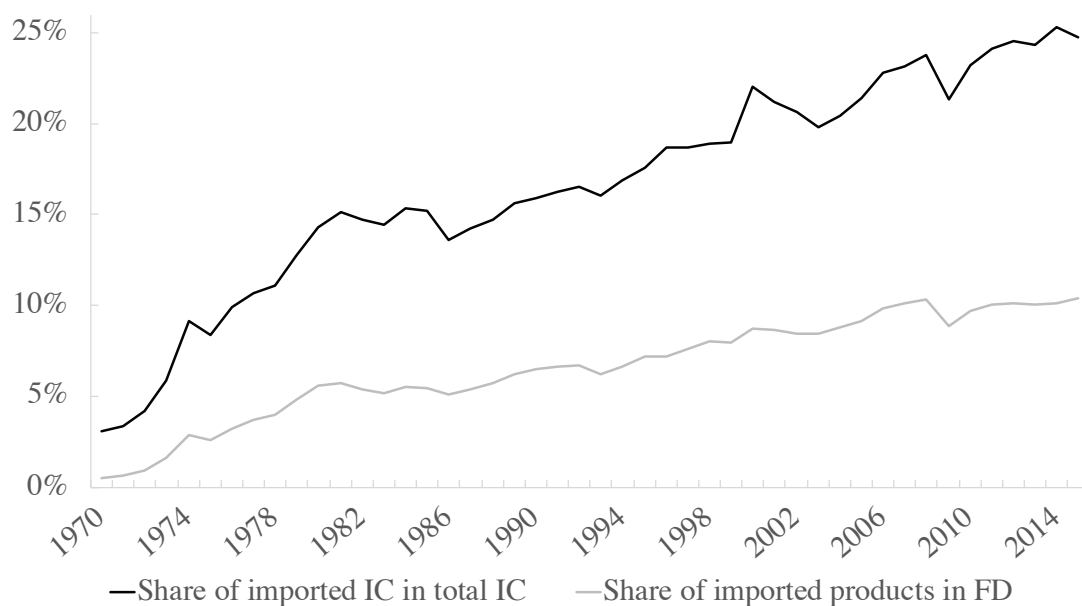


Figure 9: Share of imported intermediate consumption (IC) in total intermediate consumption and share of imported products in final demand (FD). Source: authors' computations with data from Eora 199.82 Input-Output database. Shares with data at basic prices are exhibited but results with data at purchaser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

284 The increasing internationalization of French capitalism as illustrated on figures 4-9 is identi-
 285 fied by RT as one of the main cause of Fordism's crisis from the mid-1970s. After infrastructures
 286 and capital stocks in key sectors were reconstituted, the domestic market alone became insuf-
 287 ficient to support high returns to scale, as shown by slowing productivity gains from the mid-
 288 1960s/early-1970s onwards. Exports then appeared as a mean to sustain the accumulation regime
 289 based on increasing returns. The average annual growth rate between 1960 and 1968 is 11% for
 290 imports and 7.8% for exports (Balladur, 1972, p. 13). Therefore, internationalization in the
 291 1960s initially opened up new growth opportunities and exports complemented domestic wages
 292 in the composition of effective demand steering the accumulation regime. However, the increasing
 293 importance of exports relatively to wages for steering growth turned price-competitiveness into
 294 a major concern of exporting firms (Boyer, 2015; Loiseau et al., 1977; Vidal, 2003). Guillaumet
 295 (2002) finds that, between 1850 and 2000, trade had a positive effect on growth only between
 296 1957 and 1974. The productivity gains-wages increases-domestic mass consumption loop under-
 297 lying the fordist social compromise was then broken and domestic wages became an adjustment
 298 variable. All the more so after the collapse of Bretton Woods and the emergence of the European
 299 monetary integration from 1972 onwards, with gradual constraints on exchange rates.

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

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

305 The systemic complementarity between financialization and offshoring has thus been instru-
306 mental in producing a new accumulation regime, together with the emergence of a new mode
307 of regulation that involves deep transformations in the wage-labour nexus¹³. The growth of the
308 invisible trade flows from the 1970s (figures 4-7) is a consequence of this macroeconomic process.
309 The evolution of the distribution of GVA of non-financial corporations in France substantiates
310 this comprehension. We approach financialization through the evolution of the wage and the
311 profit shares in GVA and through financial accumulation.

312 We look at the non-financial corporations (NFCs). Indeed, we assume NFCs to be the main
313 users of materials through intermediate consumption (between 1950 and 2015, the share of NFCs
314 in total intermediate consumption in monetary terms oscillates between 74 and 83 %, with an
315 increasing trend since 1997¹⁴). Four stylized facts characterize the financialization of French
316 NFCs as shown on figure 10.

¹³This 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).

¹⁴Authors' calculations from OECDStat national accounting data.

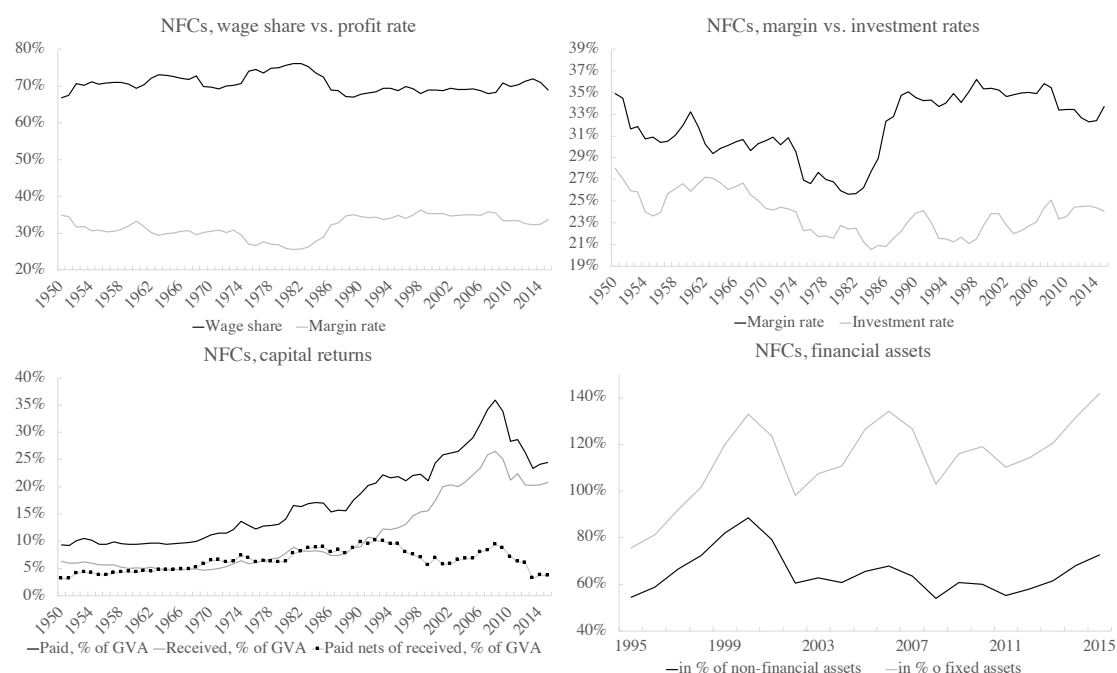


Figure 10: Wage share (compensation of employees / GVA), margin rate (gross operating surplus / GVA), investment rate (GFCF / GVA), capital returns and financial assets of non-financial corporations, 1950-2015. Capital returns paid and received are the sum of, respectively, paid and received distributed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

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

324 Second, we observe a decoupling of the margin and gross fixed capital formation rates. From
 325 1980 onwards, the close correlation between the two series is broken and they increasingly diverge.
 326 The investment rate oscillates at a level appreciably lower than during the core of the fordist era
 327 and does not follow the increase in the profit share. In line with most studies of financialization,
 328 this indicates that the increase in the profit share does not fuel investment in productive capital
 329 domestically.

330 Third, an increasing share of GVA went back to financial capital, in the form of interests and
 331 dividends (added together as capital returns on figure 10), which form the distributed profit¹⁵.

¹⁵This 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.

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

341 Fourth, this observation is further substantiated by the accumulation of financial assets,
342 whose proportion as compared to fixed assets exhibited a rising trend with important fluctuations
343 during the internet bubble and the subprimes crises. This process of financial accumulation is
344 a well-known stylized fact in the literature on financialization (Krippner, 2005; Stockhammer,
345 2004). Unfortunately, the data on financial assets are only available from 1995 onwards, which
346 limit our historical hindsight. The data nonetheless indicates an increasing financial capital
347 accumulation as compared to productive capital accumulation. Kovacic et al. (2018) refer to this
348 as an increasing financial intensity when looking at the *financial assets / value added* ratio¹⁶. Of
349 course, financial assets prices tend to inflate while non-financial assets can depreciate, especially
350 fixed assets (e.g. productive capital). The evolution of these latter ratios can then be partly
351 attributed to the appreciation of financial assets prices. This still shows a financial accumulation
352 in the form of capital gains. Interestingly, however, the evolution is much less clear when non-
353 produced non-financial assets are also considered.

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

¹⁶We 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 .

369 2019; Durand and Miroudot, 2015; Fiebiger, 2016; Ivanova, 2019; Milberg, 2008; Milberg and
370 Winkler, 2010).

371 **4 The dialectics between socio-metabolic and accumula-** 372 **tion regimes: a tentative discussion**

373 These observations remain descriptive and shed little light on the causal mechanisms linking
374 socio-metabolic and accumulation regimes. RT prioritized endogenous factors that initially en-
375 sured Fordism’s success in its analysis of the crisis (Lordon, 2002). Therefore, RT did not
376 integrate material flows for they were considered exogenous factors, e.g. oil¹⁷. This epistemolog-
377 ical stance entailed blindness to the role of materials in supporting accumulation regimes and in
378 shaping institutional compromises of the mode of regulation.

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

383 **4.1 Power of matter: The economic role of materials in underlying** 384 **accumulation regimes**

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

391 Agriculture experienced the most dramatic changes during Fordism. In 1945, more than 7.5
392 million people — over a third of the working population — worked in this sector and the country
393 had difficulty feeding the population (ration stamps were maintained until 1949). Successive
394 governments encouraged a strong recovery in production, which required an improvement in
395 productivity. This was possible through cheap oil imports that allowed for strong mechanization
396 and massive use of fossil-based inputs, e.g. fertilizers. As a consequence, from 1950 to 1974,
397 the agricultural population decreased from 29% to 10% of the total working population (Allaire,
398 1988). Agriculture lost an average of 135 000 jobs per year between 1944 and 1973.

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

¹⁷According 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.*”

401 compromise until the beginning of the 1970s. Agricultural exports enabled the trade balance
402 to be in equilibrium between 1960 and 1968 together with the automotive industry. In the late
403 1960s, exports growth was mainly due to exceptionally high exports of agricultural products while
404 growth in exports of industrial products had slowed down (Balladur, 1972; de Ravignan, 1980).
405 The orientation of agriculture towards exports and its specialization steered high productivity
406 gains that freed up labour absorbed by the industrial sector. Material intensive industries, e.g.
407 mining, metallurgy and the automotive industry, applying taylorist techniques, steered high
408 productivity gains in the manufacturing sector that formed the backbone of the fordist social
409 compromise. Automotive industry’s exports were largely in surplus and amounted for most of
410 the trade surplus for the period 1959-1973 (Mistral, 1975).

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

424 The transition to the more intensive neoliberal accumulation and socio-metabolic regime has
425 in no way meant a rupture with the extensive and fossilist fordist regime. This is especially true
426 for the *mode of living*, that is the “*dominant patterns of production, distribution, and consumption*
427 *that are deeply rooted in the everyday practices of the upper and middle classes of the global*
428 *North and increasingly in the emerging countries of the global South*” (Brand and Wissen, 2012,
429 p. 548). Rather, the more domestic materiality of French capitalism inherited from Fordism is
430 partly substituted for and partly complemented by the more offshore materiality of the neoliberal
431 accumulation regime. Therefore, in terms of socio-metabolic evolution, it seems more relevant
432 to speak of a metabolic addition than of a metabolic transition between the two regimes¹⁸.

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

¹⁸This 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.

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

440 **4.2 Matter of power: The political role of materials in shaping modes** 441 **of regulation**

442 Despite their role in sustaining the fordist social compromise, materials had ambiguous effects on
443 the institutionalized compromises regulating the accumulation regime. To some extent, materials
444 were therefore also instrumental in the shift towards Neoliberalism (Cahen-Fourot and Durand,
445 2016; Debeir et al., 2013; Huber, 2013; Mitchell, 2011).

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

461 Coal mines were nationalized in 1946 (creation of the public establishment *Charbonnages de*
462 *France*) and coal production was made a national priority (noticeable in the first French *Plans*).
463 Though decreasing, coal still dominated the energy mix until 1963. In 1958, France produced 59
464 Mt of coal and the country had about 145 000 miners. The transition from coal to oil — from
465 a domestic material to an imported commodity — clearly impacted the fordist regime. The low
466 price of oil implied overproduction of coal in the late 1950s. This resulted in the Jeanneney Plan
467 (1959) that explicitly decided to decrease coal production and to reduce the workforce in this
468 sector by closing several coal mines and investing in new oil refineries. In 1962, only two years
469 after the Plan was launched, coal production declined to 52 Mt and the workforce to 120 000.

470 The addition of oil to the energy mix and its progressive emergence as the main energy
471 carrier had ambiguous effects on the mode of regulation. In contrast to coal, oil extraction
472 and distribution are not labour intensive and oil was mainly imported. The peculiarities of oil
473 exploitation decreased the energy workers' power to push further socio-political demands. There
474 is thus an oil paradox: While cheap and abundant oil enabled the productivity gains providing
475 the foundations of the fordist social compromise, it shifted the power balance between labour

476 and capital, thus laying the ground for the mutation of the wage-labour nexus that had been at
477 the core of Fordism (Cahen-Fourot and Durand, 2016; Mitchell, 2011).

478 Beyond coal and oil, material intensive industries also conferred strong structural and asso-
479 ciational powers upon workers (Silver, 2003; Tronti, 1977; Wright, 2000). In the 1960s, France
480 ranked fourth among European steel producers with approximately 20 Mt. There were more
481 than 100 000 workers in the steel sector in the Lorraine region alone, whereas there are less than
482 8000 nowadays (Raggi, 2013). The harmful nature of the work and the high costs of extraction
483 lead to substituting imports to domestic production. The decline began in the 1960s with steel
484 from Lorraine losing attractiveness because of imported minerals exhibiting cheaper cost and
485 higher concentration in iron, up to 50-60%. Globalization made price competitiveness key and
486 signalled the shift in French capitalism internationalization from exports complementing domes-
487 tic demand to offshoring of heavy industries' production. In the aftermath of Fordism, heavy
488 industries concentrating unionized workers and materials were relocated to a great extent. The
489 end of coal and iron ore mining undoubtedly weakened workers. Together with oil, it paved the
490 way for the transformation of the wage-labour nexus and the challenging of the fordist social
491 compromise that would result in the advent of a new mode of regulation supporting the neoliberal
492 accumulation regime.

493 As mediating tools in the labour-capital relation, materials are instrumental in shaping insti-
494 tutionalised compromises emerging from social struggles and in enabling transformations in the
495 modes of regulation supporting accumulation regimes. Drawing from Cahen-Fourot and Durand
496 (2016), we suggest that the offshoring-financialization nexus affected the mediating role of mate-
497 rials in the labour-capital relation through triggering the relocation of key material flows abroad.
498 Our hypothesis is that the offshoring-financialization nexus reduced the power of French workers
499 to push their socio-political agenda in decreasing their ability to control the use, production and
500 distribution of key material flows. In a self-reinforcing loop, this loss in structural and associa-
501 tional powers — exemplified by the decrease in the wage share and in the unionization rate, that
502 went from 30% in 1949 to 17-20% between 1960 and 1975 and then to around 11% in 2016¹⁹ —
503 may have in turn affected the ability of workers to oppose the process of financialization and the
504 offshoring of industries²⁰.

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

¹⁹According 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.

²⁰Another 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>

511 significant correlations between each other, illustrating the systemic complementarity between
512 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% (**).

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

516 5 Conclusion

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

527 Second, we attempt at linking the shift from Fordism to Neoliberalism and the offshoring-
528 financialization nexus with the evolution of the material basis of French capitalism. We discuss
529 tentatively how the offshoring of production and the financialization of French non-financial
530 corporations, the disappearance of coal and the shrinking of heavy industries might have affected
531 the mediating role of materials in the labour-capital relation and the structural and associational

532 powers of workers. Fordism’s success was enabled by endogenous socio-economic factors — high
533 productivity gains, domestic mass production and mass consumption, exports complementing
534 domestic demand, strong redistribution mechanisms — that have their counterpart as a socio-
535 metabolic regime in the form of material inputs. Fordism’s crisis came through these very same
536 factors, with declining productivity gains combining with rising internationalization eventually
537 turning into the offshoring-financialization nexus while French capitalism became increasingly
538 dependent on imported material inputs.

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

548 Yet, our work is not exempt of methodological and theoretical limits. First, we neglect the
549 waste and emissions part of socio-metabolic regimes. Second, MFA minimizes the importance
550 of nuclear energy²¹ because it relies on ‘light’ non-renewable resources, e.g. uranium (Hecht,
551 2014). The impact of the growth of nuclear energy on the wage-labour nexus and the transition
552 from Fordism to Neoliberalism is unclear. Third, our estimate of the material footprint will be
553 much improved once input-output tables prior to 1970 become available (Lenzen et al., 2013).
554 Fourth, our hypothesis regarding the combined effects of the offshoring-financialization nexus and
555 of materials on the evolution of institutionalized compromises remain to be thoroughly tested.
556 Fifth, the current paper merely insisted upon the wage-labour nexus but other institutional forms
557 — the monetary regime, the form of the state, the form of competition, the insertion into the
558 international regime and the social relation to the environment — were largely ignored.

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

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

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

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582 References

- 583 Aglietta, M. (2015). *A Theory of Capitalist Regulation: The US Experience* (Third ed.). London:
584 Verso.
- 585 Allaire, G. (1988). Le modèle de développement agricole des années 1960. *Économie ru-*
586 *rale* 184(1), 171–181.
- 587 Auvray, T. and J. Rabinovich (2019). The financialisation–offshoring nexus and the capital
588 accumulation of US non-financial firms. *Cambridge Journal of Economics* 43(5), 1183–1218.
- 589 Balladur, J.-P. (1972). Les échanges extérieurs de la France entre 1960 et 1970. *Economie et*
590 *Statistique* 31(1), 11–21.
- 591 Bonneuil, C. and J.-B. Fressoz (2016). *L'évènement Anthropocène. La Terre, l'histoire et Nous*.
592 Paris: Points.
- 593 Boyer, R. (2015). *Économie politique des capitalismes. Théorie de la régulation et des crises*.
594 Paris: La Découverte.
- 595 Boyer, R. and Y. Saillard (2002). *Regulation Theory: The State of the Art*. Routledge.
- 596 Brand, U. and M. Wissen (2012). Global Environmental Politics and the Imperial Mode of
597 Living: Articulations of State–Capital Relations in the Multiple Crisis. *Globalizations* 9(4),
598 547–560.
- 599 Brand, U. and M. Wissen (2013). Crisis and continuity of capitalist society–nature relation-
600 ships: The imperial mode of living and the limits to environmental governance. *Review of*
601 *International Political Economy* 20(4), 687–711.
- 602 Bruckner, M., S. Giljum, C. Lutz, and K. S. Wiebe (2012). Materials embodied in interna-
603 tional trade – Global material extraction and consumption between 1995 and 2005. *Global*
604 *Environmental Change* 22(3), 568–576.

- 605 Cahen-Fourot, L. (2020). Contemporary capitalisms and their social relation to the environment.
606 *Ecological Economics* 172.
- 607 Cahen-Fourot, L., E. Campiglio, E. Dawkins, A. Godin, and E. Kemp-Benedict (2020). Looking
608 for the Inverted Pyramid: An Application Using Input-Output Networks. *Ecological Eco-*
609 *nomics* 169.
- 610 Cahen-Fourot, L. and C. Durand (2016). La transformation de la relation sociale à l'énergie du
611 fordisme au capitalisme néolibéral : Une exploration empirique et macro-économique comparée
612 dans les pays riches (1950-2010). *Revue de la régulation* 20.
- 613 Chen, W.-Q. and T. E. Graedel (2015). In-use product stocks link manufactured capital to
614 natural capital. *Proceedings of the National Academy of Sciences* 112(20), 6265–6270.
- 615 Chester, L. (2010). Determining the economic-environment relation: A regulationist approach.
616 *International Journal of Green Economics* 4(1), 17–42.
- 617 de Ravnian, F. (1980). L'agriculture, pétrole vert de la France ? *Économie rurale* 139(1),
618 31–38.
- 619 Debeir, J.-C., J.-P. Deléage, and D. Hémerly (2013). *Une histoire de l'énergie. Les servitudes de*
620 *la puissance* (Second ed.). Paris: Flammarion.
- 621 Dittrich, M., S. Bringezu, and H. Schütz (2012). The physical dimension of international trade,
622 part 2: Indirect global resource flows between 1962 and 2005. *Ecological Economics* 79, 32–43.
- 623 Duménil, G. and D. Lévy (2014). *La Grande Bifurcation: En Finir Avec Le Néolibéralisme.*
624 Paris: La Découverte.
- 625 Durand, C. and S. Miroudot (2015). Is labour the fall guy of a financial-led globalisation? A
626 cross-country inquiry on globalisation, financialisation and employment at the industry level.
627 *Review of World Economics* 151(3), 409–432.
- 628 Eurostat (2015). Handbook for estimating raw material equivalents. Technical report, Eurostat.
- 629 Eurostat (2018). *Economy-Wide Material Flow Accounts Handbook.* Publications Office of the
630 European Union.
- 631 Feenstra, R. C. and G. H. Hanson (1999). The Impact of Outsourcing and High-Technology
632 Capital on Wages: Estimates For the United States, 1979–1990. *The Quarterly Journal of*
633 *Economics* 114(3), 907–940.
- 634 Feenstra, R. C. and J. B. Jensen (2012, October). Evaluating estimates of materials offshoring
635 from US manufacturing. *Economics Letters* 117(1), 170–173.
- 636 Fiebiger, B. (2016). Rethinking the Financialisation of Non-Financial Corporations: A Reap-
637 praisal of US Empirical Data. *Review of Political Economy* 28(3), 354–379.
- 638 Fischer-Kowalski, M. and H. Haberl (1993). Metabolism and Colonization. Modes of Produc-
639 tion and the Physical Exchange between Societies and Nature. *Innovation in Social Sciences*
640 *Research* 6(4), 415–442.
- 641 Fischer-Kowalski, M. and H. Haberl (1997). Tons, joules, and money: Modes of production and
642 their sustainability problems. *Society & Natural Resources* 10(1), 61–85.
- 643 Freeman, R. (2007). The great doubling: The challenge of the new global labor market. In

- 644 J. Edwards, M. Crain, and A. L. Kalleberg (Eds.), *Ending Poverty in America: How to*
645 *Restore the American Dream*. New York: The New Press.
- 646 French, S., A. Leyshon, and T. Wainwright (2011). Financializing space, spacing financialization.
647 *Progress in Human Geography* 35(6), 798–819.
- 648 Giljum, S., M. Bruckner, and A. Martinez (2015). Material Footprint Assessment in a Global
649 Input-Output Framework: Material Footprint Assessment in a Global Input-Output Frame-
650 work. *Journal of Industrial Ecology* 19(5), 792–804.
- 651 Giljum, S., M. Dittrich, M. Lieber, and S. Lutter (2014). Global Patterns of Material Flows
652 and their Socio-Economic and Environmental Implications: A MFA Study on All Countries
653 World-Wide from 1980 to 2009. *Resources* 3(1), 319–339.
- 654 Görg, C., C. Plank, D. Wiedenhofer, A. Mayer, M. Pichler, A. Schaffartzik, and F. Krausmann
655 (2020). Scrutinizing the Great Acceleration: The Anthropocene and its analytic challenges for
656 social-ecological transformations. *The Anthropocene Review* 7(1), 42–61.
- 657 Guillaumet, P. (2002). Les relations commerciales entre la France et l’Europe depuis 1850:
658 Impact sur la croissance économique de la France. *Revue de l’OFCE* 82(3), 49.
- 659 Haberl, H., M. Fischer-Kowalski, F. Krausmann, and V. Winiwarter (2016). *Social Ecology.*
660 *Society-Nature Relations across Time and Space*. New York, NY: Springer Berlin Heidelberg.
- 661 Harvey, D. W. (2014). *Brève histoire du néolibéralisme*. Paris: Les Prairies ordinaires.
- 662 Hecht, G. (2014). *Le rayonnement de la France. Énergie nucléaire et identité nationale après la*
663 *Seconde guerre mondiale*. Paris: Amsterdam.
- 664 Hornborg, A. (2012). *Global Ecology and Unequal Exchange: Fetishism in a Zero-Sum World*.
665 Routledge.
- 666 Huber, M. (2013). Fueling Capitalism: Oil, the Regulation Approach, and the Ecology of Capital.
667 *Economic Geography* 89(2), 171–194.
- 668 Husson, M. (2012). Le néolibéralisme, stade suprême ? *Actuel Marx* 51(1), 86.
- 669 Ivanova, M. N. (2019). Inequality, financialization, and the US current account deficit. *Industrial*
670 *and Corporate Change* 28(4), 707–724.
- 671 Kovacic, Z., M. Spanò, S. L. Piano, and A. H. Sorman (2018). Finance, energy and the decoupling:
672 An empirical study. *Journal of Evolutionary Economics* 28(3), 565–590.
- 673 Krausmann, F., D. Wiedenhofer, C. Lauk, W. Haas, H. Tanikawa, T. Fishman, A. Miatto,
674 H. Schandl, and H. Haberl (2017). Global socioeconomic material stocks rise 23-fold over the
675 20th century and require half of annual resource use. *Proceedings of the National Academy of*
676 *Sciences* 114(8), 1880–1885.
- 677 Krippner, G. R. (2005). The financialization of the American economy. *Socio-Economic Re-*
678 *view* 3(2), 173–208.
- 679 Lazonick, W. and M. O’Sullivan (2000). Maximizing shareholder value: A new ideology for
680 corporate governance. *Economy and Society* 29(1), 13–35.
- 681 Lenzen, M., K. Kanemoto, D. Moran, and A. Geschke (2012). Mapping the Structure of the
682 World Economy. *Environmental Science & Technology* 46(15), 8374–8381.

- 683 Lenzen, M., D. Moran, K. Kanemoto, and A. Geschke (2013). Building Eora: A global multi-
684 region input-output database at high country and sector resolution. *Economic Systems Re-*
685 *search* 25(1), 20–49.
- 686 Loiseau, B., J. Mazier, and M.-B. Winter (1977). Rentabilité du capital dans les économies
687 dominantes : Des tensions accrues. *Economie et statistique* 86(1), 39–54.
- 688 Lordon, F. (2002). Formalising regulationist dynamics and crises. In R. Boyer and Y. Saillard
689 (Eds.), *Regulation Theory: The State of the Art*, pp. 174–180. Routledge.
- 690 Lutter, S., S. Giljum, and M. Bruckner (2016). A Review and Comparative Assessment of
691 Existing Approaches to Calculate Material Footprints. *Ecological Economics* 127, 1–10.
- 692 Magalhães, N., J.-B. Fressoz, F. Jarrige, T. Le Roux, G. Levillain, M. Lyautey, G. Noblet, and
693 C. Bonneuil (2019). The Physical Economy of France (1830–2015). The History of a Parasite?
694 *Ecological Economics* 157, 291–300.
- 695 Milberg, W. (2008). Shifting sources and uses of profits: Sustaining US financialization with
696 global value chains. *Economy and Society* 37(3), 420–451.
- 697 Milberg, W. and D. Winkler (2010). Financialisation and the dynamics of offshoring in the USA.
698 *Cambridge Journal of Economics* 34(2), 275–293.
- 699 Miller, R. E. and P. D. Blair (2009). *Input-Output Analysis: Foundations and Extensions* (2nd
700 ed ed.). Cambridge [England] ; New York: Cambridge University Press.
- 701 Mistral, J. (1975). Vingt ans de redéploiement du commerce extérieur. *Economie et Statis-*
702 *tique* 71(1), 23–40.
- 703 Mitchell, T. (2011). *Carbon Democracy: Political Power in the Age of Oil*. London: Verso.
- 704 Morin, F. (2000). A transformation in the French model of shareholding and management.
705 *Economy and Society* 29(1), 36–53.
- 706 Muñoz, P., S. Giljum, and J. Roca (2009). The Raw Material Equivalents of International Trade:
707 Empirical Evidence for Latin America. *Journal of Industrial Ecology* 13(6), 881–897.
- 708 Muradian, R., M. Walter, and J. Martinez-Alier (2012). Hegemonic transitions and global shifts
709 in social metabolism: Implications for resource-rich countries. Introduction to the special
710 section. *Global Environmental Change* 22(3), 559–567.
- 711 OECD (2019). *Global Material Resources Outlook to 2060: Economic Drivers and Environmental*
712 *Consequences*. OECD Publishing.
- 713 Pauliuk, S. and D. B. Müller (2014). The role of in-use stocks in the social metabolism and in
714 climate change mitigation. *Global Environmental Change* 24, 132–142.
- 715 Peters, G. P. (2008). From production-based to consumption-based national emission inventories.
716 *Ecological Economics* 65(1), 13–23.
- 717 Piñero, P., M. Bruckner, H. Wieland, E. Pongrácz, and S. Giljum (2019). The raw material basis
718 of global value chains: Allocating environmental responsibility based on value generation.
719 *Economic Systems Research* 31(2), 206–227.
- 720 Pottier, A. (2014, January). *L'économie dans l'impasse climatique : développement matériel,*
721 *théorie immatérielle et utopie auto-stabilisatrice*. Doctorat, EHESS, Paris.

- 722 Raggi, P. (2013). Industrialisation, désindustrialisation, ré-industrialisation en Europe: Le cas
723 de la sidérurgie lorraine (1966-2006). *Rives méditerranéennes* 46, 11–28.
- 724 Schandl, H., M. Fischer-Kowalski, J. West, S. Giljum, M. Dittrich, N. Eisenmenger, A. Geschke,
725 M. Lieber, H. Wieland, A. Schaffartzik, F. Krausmann, S. Gierlinger, K. Hosking, M. Lenzen,
726 H. Tanikawa, A. Miatto, and T. Fishman (2018). Global Material Flows and Resource Pro-
727 ductivity: Forty Years of Evidence. *Journal of Industrial Ecology* 22(4), 827–838.
- 728 Silver, B. J. (2003). *Forces of Labor: Workers' Movements and Globalization since 1870*. Cam-
729 bridge ; New York: Cambridge University Press.
- 730 Steffen, W., K. Richardson, J. Rockström, S. E. Cornell, I. Fetzer, E. M. Bennett, R. Biggs, S. R.
731 Carpenter, W. de Vries, C. A. de Wit, C. Folke, D. Gerten, J. Heinke, G. M. Mace, L. M.
732 Persson, V. Ramanathan, B. Reyers, and S. Sorlin (2015). Planetary boundaries: Guiding
733 human development on a changing planet. *Science* 347(6223), 736–748.
- 734 Stockhammer, E. (2004). Financialisation and the slowdown of accumulation. *Cambridge Journal*
735 *of Economics* 28(5), 719–741.
- 736 Tronti, M. (1977). Marx à Détroit. In *Ouvriers et Capital*. Paris: Christian Bourgeois.
- 737 Vidal, J.-F. (2003). Régimes de croissance post fordistes: Comparaison des Etats-Unis, du Japon
738 et de la France. In *Forum de La Régulation*.
- 739 Wiedenhofer, D., T. Fishman, C. Lauk, W. Haas, and F. Krausmann (2019). Integrating Material
740 Stock Dynamics Into Economy-Wide Material Flow Accounting: Concepts, Modelling, and
741 Global Application for 1900–2050. *Ecological Economics* 156, 121–133.
- 742 Wiedenhofer, D., E. Rovenskaya, W. Haas, F. Krausmann, I. Pallua, and M. Fischer-Kowalski
743 (2013). Is there a 1970s Syndrome? Analyzing Structural Breaks in the Metabolism of Indus-
744 trial Economies. *Energy Procedia* 40, 182–191.
- 745 Wiedenhofer, D., J. K. Steinberger, N. Eisenmenger, and W. Haas (2015). Maintenance and
746 Expansion: Modeling Material Stocks and Flows for Residential Buildings and Transportation
747 Networks in the EU25. *Journal of Industrial Ecology* 19(4), 538–551.
- 748 Wiedmann, T., J. Minx, J. Barrett, and M. Wackernagel (2006). Allocating Ecological Footprints
749 to Final Consumption Categories with Input–Output Analysis. *Ecological Economics* 56(1),
750 28–48.
- 751 Wiedmann, T. O., H. Schandl, M. Lenzen, D. Moran, S. Suh, J. West, and K. Kanemoto (2015).
752 The material footprint of nations. *Proceedings of the National Academy of Sciences* 112(20),
753 6271–6276.
- 754 Wright, E. O. (2000). Working-Class Power, Capitalist-Class Interests, and Class Compromise.
755 *American Journal of Sociology* 105(4), 957–1002.
- 756 Zuindeau, B. (2007). Régulation school and environment: Theoretical proposals and avenues of
757 research. *Ecological Economics* 62(2), 281–290.

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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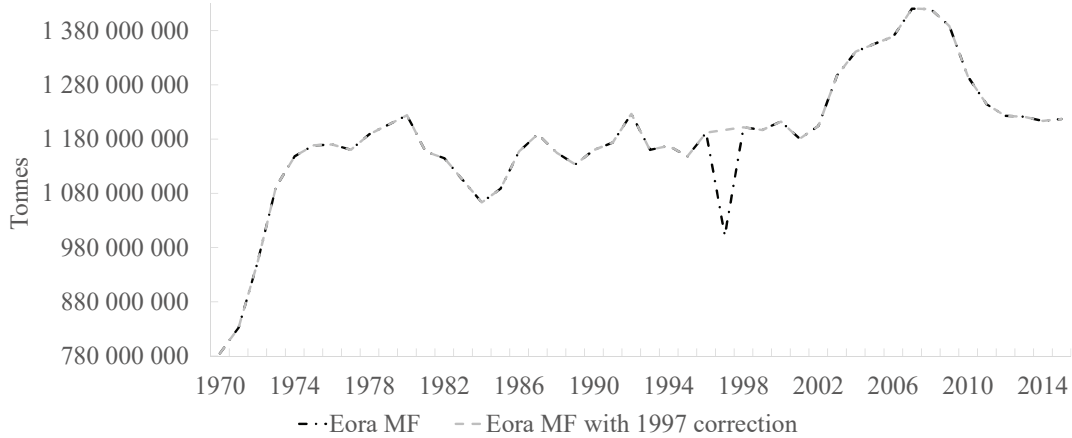


Figure A1: Material footprint from 1970 to 2015 in tonne, with and without the 1997 correction. Source: Data from Eora input-output database (Lenzen et al., 2013).

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 $j \in \{biomass, metal\ ores, non-metallic\ ores, fossil\ fuels\}$:

$$MF_{j,t} = DE_{j,t} + RTB_{j,t} \quad (1)$$

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 $t \in \{1948, \dots, 2015\}$, we define

$$\alpha_{j,t} = \frac{RTB_{j,t}}{PTB_{j,t}} \quad (2)$$

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 $(\alpha_{j,1976}, \dots, \alpha_{j,2015})$. 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:

$$\bar{\alpha}_j = \text{median}(\alpha_{j,t}, t = 1976, \dots, 2015) \quad (3)$$

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 $t \in \{1948, \dots, 1975\}$ and for each material category j :

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

and

$$\widehat{MF}_{j,t} = DE_{j,t} + \widehat{RTB}_{j,t} \quad (5)$$

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 $j \in \{\text{biomass}, \text{metal ores}, \text{non-metallic ores}, \text{fossil fuels}\}$, for each year $t \in \{1970, \dots, 2015\}$.

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 all¹.

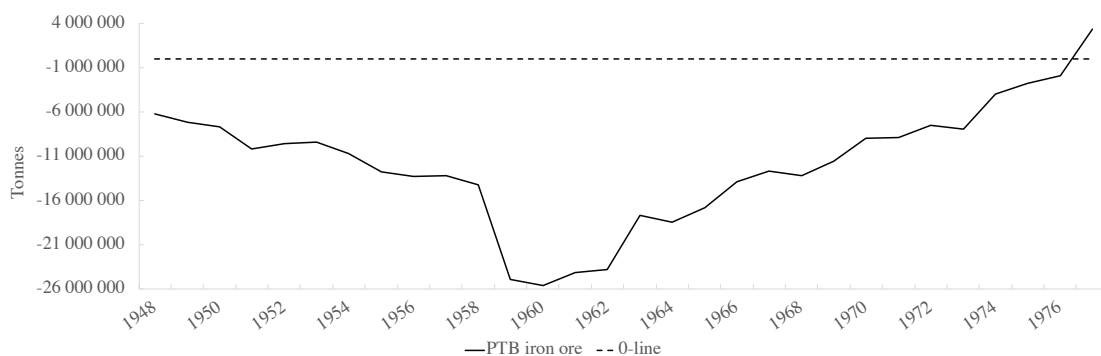


Figure A2: Physical trade balance of iron ore (1948-1977). Data from Magalhães et al. (2019).

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.

¹A 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).

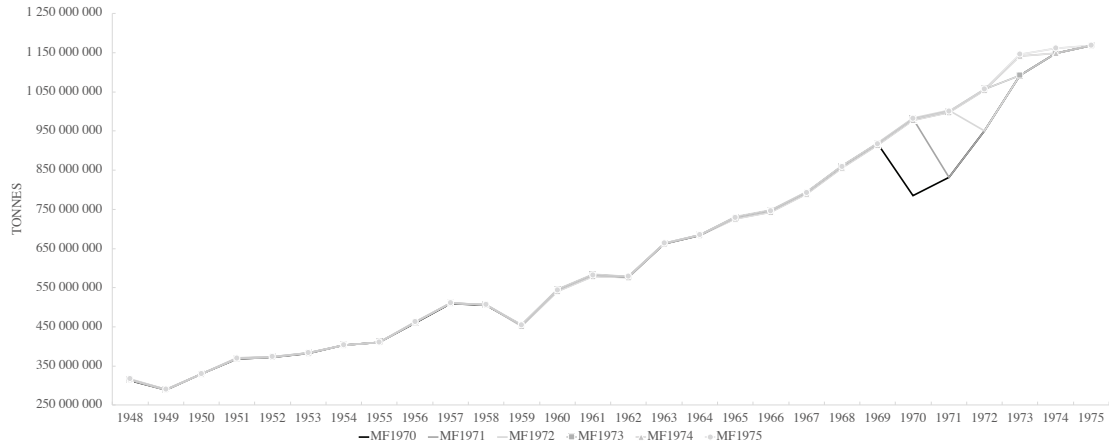


Figure A3: Comparison of material footprint estimates 1970 to 1975.

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. Obviously this approach is limited but we consider it accurate enough to estimate the main trends.

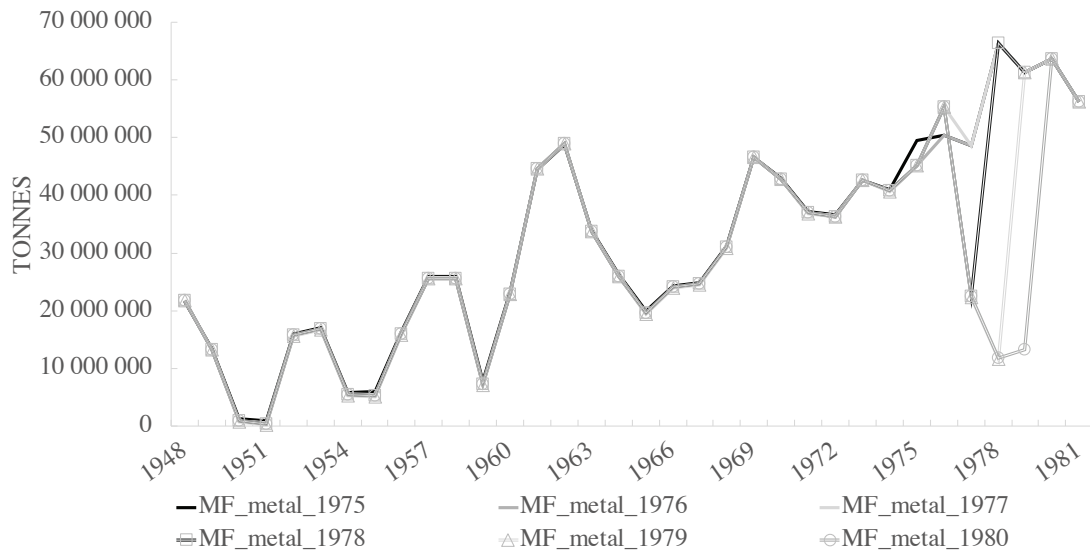


Figure A4: Comparison of MF metal estimates 1975 to 1980.

2 Relative trajectories in terms of GVA: disaggregated materials

When disaggregating 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.

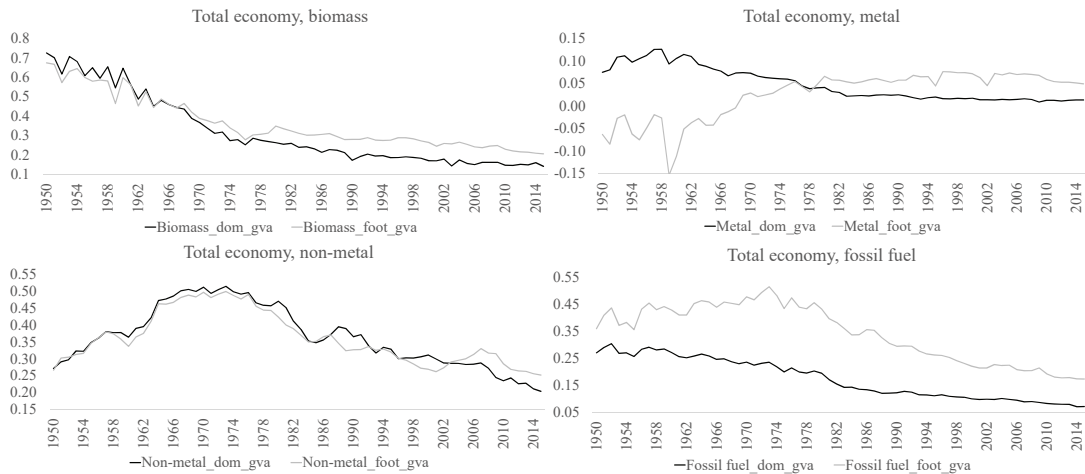


Figure A5: Disaggregated domestic and footprint material intensity of GVA at factors cost in kilo per 2010 euro.

References

- Eurostat (2015). Handbook for estimating raw material equivalents. Technical report, Eurostat.
- Eurostat (2018). *Economy-Wide Material Flow Accounts Handbook*. Publications Office of the European Union.
- Giljum, S., M. Bruckner, and A. Martinez (2015). Material Footprint Assessment in a Global Input-Output Framework: Material Footprint Assessment in a Global Input-Output Framework. *Journal of Industrial Ecology* 19(5), 792–804.
- Giljum, S., C. Lutz, and A. Jungnitz (2007). A Multi-Regional Environmental Input-Output Model to Quantify Embodied Material Flows. *GWS mbH, Vienna*, 1–35.
- Lenzen, M., K. Kanemoto, D. Moran, and A. Geschke (2012). Mapping the Structure of the World Economy. *Environmental Science & Technology* 46(15), 8374–8381.
- Lenzen, M., D. Moran, K. Kanemoto, and A. Geschke (2013). Building Eora: A global multi-region input-output database at high country and sector resolution. *Economic Systems Research* 25(1), 20–49.
- Lutter, S., S. Giljum, and M. Bruckner (2016). A Review and Comparative Assessment of Existing Approaches to Calculate Material Footprints. *Ecological Economics* 127, 1–10.
- Magalhães, N., J.-B. Fressoz, F. Jarrige, T. Le Roux, G. Levillain, M. Lyautey, G. Noblet, and C. Bonneuil (2019). The Physical Economy of France (1830–2015). The History of a Parasite? *Ecological Economics* 157, 291–300.
- Schaffartzik, A., A. Mayer, N. Eisenmenger, and F. Krausmann (2016). Global Patterns of Metal Extractivism, 1950–2010: Providing the Bones for the Industrial Society’s Skeleton. *Ecological Economics* 122, 101–110.
- Wiedmann, T. O., H. Schandl, M. Lenzen, D. Moran, S. Suh, J. West, and K. Kanemoto (2015). The material footprint of nations. *Proceedings of the National Academy of Sciences* 112(20), 6271–6276.



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