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Taxonomy-alignment and transition risk: a country-level approach

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Executive summary

The European Union (EU) has developed the EU Taxonomy for sustainable activities to provide a definition of 'green' economic activities, which is used as a basis to assess the greenness of financial investments. However, data on Taxonomy-alignment are only becoming available for larger EU firms, and several challenges remain open to improve the usability of this tool by financial institutions.

In parallel, regulators and supervisors, as well as individual financial institutions, have been increasingly paying attention to financial risks stemming from climate change. In particular, a key question regards the exposure of particular investments, portfolios, financial institutions and the financial system as a whole to climate-related transition risk, i.e. the risk linked to certain economic activities which will need to be abandoned in the low-carbon transition, such as those involving fossil fuels.

Against this background, in a previous paper (Alessi and Battiston (2022a)) we proposed a methodology to estimate the greenness, or Taxonomy-alignment, and the exposure to transition risk of financial institutions' investments in the absence of granular information on investee and borrower companies. In particular, we developed Taxonomy-alignment coefficients (TACs) for climate change mitigation and Transition-risk exposure coefficients (TECs) that are specific to each economic sector and largely based on the definitions provided in the Taxonomy.

In this paper, we overcome one of the main limitations of TACs and TECs as proposed in Alessi and Battiston (2022a), i.e. their focus on the EU as a whole. In particular, while continuing to focus on climate change mitigation, we develop country-specific coefficients for individual EU Member States and for several non-EU countries.

Based on country-level coefficients, we provide an assessment of the Taxonomy-alignment and exposure to transition risk of each economic sector across countries. Moreover, by applying these coefficients to confidential security-by-security data from the European Central Bank on stock and bond holdings of EU investors, we estimate the exposure of each investor category in each country to green and harmful activities.

While confirming the findings of the previous paper, i.e. an average Taxonomy-alignment of around 3% and an average exposure to transition risk at around 11%, the empirical application shows that the exposure to transition risk of less regulated financial institutions has more than tripled from 2014 to 2023 to around 18% of total exposure, and 20% of their portfolio holdings. Looking at the cross-section of holders, the levels of Taxonomy alignment and transition risk exposure are largely heterogeneous across sectors and countries, in some cases even within the same sector.

In perspective, both estimates at the sector and investor level are needed to assess the speed at which financial markets are moving towards green and away from highly-emitting activities.

Taxonomy alignment and transition risk: a country-level approach *

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Abstract

When firm-level information is not available, the greenness of financial portfolios, in terms of alignment to the EU Taxonomy, and their exposure to climate-related transition risk need to be estimated with a top-down approach. We improve the accuracy of available estimates by providing country-specific coefficients for both dimensions, based on homogeneous definitions of greenness and transition risk across countries. An application on confidential data from the European Central Bank shows that the exposure to transition risk of less regulated financial institutions has more than tripled from 2014 to 2023. Moreover, we show that the levels of Taxonomy alignment and transition risk exposure are largely heterogeneous across countries and sectors.

Keywords: greenness, climate-related transition risk, climate-related financial disclosures, EU Taxonomy, green financial flows.

J.E.L. classification: G2; G3; Q54

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1 Introduction

The share of global financial assets under management deemed as 'green' under one or more labels has been steadily growing in recent years. This development reflects the increased demand by institutional and private investors for sustainable finance. Drivers for increased demand include compliance with new regulatory standards and changes in preferences. On the other hand, there has been a lack, until recently, of common and science-based approaches to define the greenness of financial investments. This is critical because the achievement of sustainability goals requires methods to measure greenness that are transparent, replicable and widely accepted. The European Union (EU) has developed the EU Taxonomy for sustainable activities to provide a definition of 'green' economic activities, which is used as a basis to assess the greenness of financial investments. However, data on Taxonomy-alignment are only becoming available for larger EU firms, and several challenges remain open to improve the usability of this tool by financial institutions.

In parallel, regulators and supervisors, as well as individual financial institutions, have been increasingly paying attention to financial risks stemming from climate change. In particular, a question that is asked more and more often regards the exposure of particular investments, portfolios, financial institutions and the financial system as a whole to climate-related transition risk. This is the risk linked to certain economic activities which will need to be abandoned in the low-carbon transition, such as those involving fossil fuels, but also those involving obsolete and high-emitting production processes. It should be stressed that while particular economic *activities* will need to (almost) disappear, this does not at all mean that particular *firms* will need to disappear. In fact, companies who are currently carrying out highly-emitting activities can develop credible transition plans and implement them, in order to become progressively less dependent on high-carbon activities and improve their environmental performance, eventually becoming green. Hence, while these companies are in principle exposed to transition risk, this risk may not materialize if the companies themselves transition towards low-carbon. For this reason, investors should carry out a careful assessment of each individual company and its transition plan. In this context, Taxonomy alignment acts as a shield against transition risk, as it shows that the activities carried out by a given firm, which could be in principle exposed to transition risk, are actually compatible with the transition. Also in the case of transition risk, however, firm-level information is often lacking and surely not available on a large scale. At the same time, estimates of financial institutions' exposures to transition risks are needed, not least for prudential purposes.

Against this background, in Alessi and Battiston (2022a) we propose a methodology to estimate the greenness, or Taxonomy-alignment, and the exposure to transition risk of financial institutions' investments in the absence of granular information on investee and borrower companies. In particular, we develop Taxonomy-alignment coefficients (TACs) for climate change mitigation and Transition-risk exposure coefficients (TECs) that are specific to each economic sector and largely based on the definitions provided in the Taxonomy. As such, TECs reflect a broader definition of transition risk than the one generally used in the literature, as the emphasis is not only on carbon emissions but also on energy inefficiency (for example, when assessing buildings), and are therefore more in line with the definition of transition risk underlying international and European climate-related and sustainability disclosure standards. TACs and TECs can be used to characterize greenness and transition-risk exposure of financial portfolios in the absence of firm-level data on Taxonomy-alignment and exposure to transition risk, as the only information that is needed is the economic sector where the non-financial counterpart is active.

In this paper, we overcome one of the main limitations of TAC and TEC as proposed in Alessi and Battiston (2022a), i.e. their focus on the EU as a whole. In particular, while continuing to focus on climate change mitigation, we develop country-specific coefficients for individual EU Member States and for several non-EU countries. This is important because TAC and TEC are meant to estimate the Taxonomy-alignment and transition-risk exposure of economic sectors, which can vary across countries for a given economic sector. For example, the TAC and TEC associated with electricity production are based on the share of renewable and fossil energy, respectively, which vary widely across countries. Hence, country-specific TAC and TEC, to be used based on the location of the investee company, yield more accurate estimates than coefficients based on the average EU level.

The contribution of the paper is twofold. First, by developing country-specific coefficients, we provide an assessment of the Taxonomy-alignment and exposure to transition risk of each economic sector across countries. To our knowledge, this information was not available so far in a structured fashion, and for some sectors was not available at all. Second, we apply these coefficients to confidential security-by-security data from the European Central Bank on stock and bond holdings of EU investors. Based on this data, we are able to estimate the exposure of each investor category in each country to green and harmful activities. In perspective, both estimates - at the sector and investor level - are needed to assess the speed at which financial markets are moving towards green and away from highly-emitting activities. The empirical application shows that the exposure to transition risk of less regulated financial institutions has more than tripled from 2014 to 2023 to around 18% of total exposure, and 20% of their portfolio holdings. Looking at the cross-section of holders, the levels of Taxonomy alignment and transition risk exposure are largely heterogeneous across sectors and countries, in some cases even within the same sector.

The paper is structured as follows. Section 2 provides some policy background on the EU Taxonomy and on relevant corporate disclosures. In Section 3, we explain how we derive country-specific standardized coefficients for the estimation of Taxonomy-alignment and exposure to transition risk. In Section 4 we describe the data used in the empirical application on EU investor's holdings, while Section 5 discusses the results. Section 6 concludes.

2 Policy background

The EU Taxonomy Regulation[1] adopted in 2020 establishes a framework to facilitate sustainable investment by providing a clear definition of 'sustainable' activities. So far, the Taxonomy has been developed with respect to the environmental dimension, which comprises the following six objectives: i) climate change mitigation; ii) climate

[1] Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 *(OJ L 198, 22.6.2020, p. 13-43).*

change adaptation; iii) sustainable use and protection of water and marine resources; iv) transition to a circular economy; v) pollution prevention and control; and vi) protection and restoration of biodiversity and ecosystems. In particular, a large list of green activities relevant for the first two objectives, has already become EU law.[2]

An economic activity is defined green in the Taxonomy if it complies with the following requirements: i) it provides a substantial contribution (SC) to at least one of the six objectives mentioned above; ii) it does no significant harm (DNSH) to any of the other objectives; and iii) it complies with a set of minimum social safeguards (MMS). For the SC and DNSH conditions, technical screening criteria are provided, which may take the form of quantitative thresholds (e.g. in terms of maximum CO2 emissions). However, in several cases and especially with respect to DNSH, they make more generic references to existing EU legislation or consist in high-level, qualitative requirements (see Hoepner and Schneider (2022)).

Based on the Taxonomy Regulation, all large firms, including financial institutions, need to disclose on the Taxonomy alignment of their business. In particular, as of 2022 it is mandatory to disclose the share of a company's business that is Taxonomy-eligible, i.e. for which there exist criteria in the Taxonomy. 2022 disclosures refer to FY2021 and to the two Taxonomy climate objectives only. Notice that the Taxonomy-eligible share is only an upper bound for the Taxonomy-aligned share, as it needs to be tested against the SC, DNSH and MMS criteria. As of 2023, non-financial companies need to disclose the shares of their revenues, capital and operational expenditures that are Taxonomy-aligned. One year later, this obligation will extend to financial institutions.[3] Moreover, the Taxonomy Regulation also amends the Sustainable Finance Disclosure Regulation (SFDR)[4] by imposing that investment funds marketing themselves as green (the so-called Article 8 and Article 9 products) disclose on the Taxonomy alignment of their investments.

The number of firms mandated to disclose their Taxonomy-alignment is bound to increase. For the moment, concerned firms are those in the scope of the Non-Financial Reporting Directive (NFRD)[5], which are those with more than 500 employees, i.e. about 11.000 firms in the EU. The NFRD will be replaced by the Corporate Sustainability Reporting Directive (CSRD)[6], which will extend the scope of sustainability-related disclosures to all companies (also unlisted) with more than 250 employees and listed companies.[7] This includes listed SMEs, but with the exception of listed micro-companies, as well as non-EU companies generating a net turnover of EUR150mn in the EU and which have at least one subsidiary or branch in the EU, for a total of around 50.000 firms.[8] Notably, large financial firms are in the CSRD scope too.

[2]EU Taxonomy Climate Delegated Act and its Annex 1 and Annex 2 C/2021/2139 *(OJ L 442/1, 9.12.2021)*. Complementary Delegated Act C/2022/0631 amending Delegated Regulation (EU) 2021/2139 as regards economic activities in certain energy sectors and Delegated Regulation (EU) 2021/2178 as regards specific public disclosures for those economic activities.

[3]Delegated Act supplementing Article 8 of the Taxonomy Regulation C/2021/4987 *OJ L 443, 10.12.2021, p. 9–67.*

[4]Regulation (EU) 2019/2088 of the European Parliament and of the Council of 27 November 2019 on sustainability-related disclosures in the financial services sector *OJ L 317, 9.12.2019, p. 1–16*

[5]Directive 2013/34/EU of the European Parliament and of the Council of 26 June 2013.

[6]Directive of the European Parliament and of the Council amending Directive 2013/34/EU, Directive 2004/109/EC, Directive 2006/43/EC and Regulation (EU) No 537/2014, as regards corporate sustainability reporting, 2021/0104 (COD), 30 June 2022.

[7]To be precise, also companies with more than EUR20mn balance sheet total or more than EUR40mn net turnover will be in scope.

[8]For listed SMEs an opt-out would be available during a transitional period until 2028.

Against this regulatory background, even assuming that the Taxonomy-alignment that will be disclosed by CSRD non-financial companies is precise and reliable (see next section) as these disclosures will be subject to auditing, there is a practical issue that financial institutions will face. Large parts of banks', insurers' and investment funds' exposures are to counterparts which have no obligation to disclose based on the Taxonomy, i.e. (unlisted) SMEs and most non-EU corporates, as well as governments and central banks. In particular, even with the scope enlargement due to the CSRD, there will still be 25 million SMEs in the EU which will have no obligation to report on their Taxonomy-alignment.[9] They can do that on a voluntary basis, and to this aim, simplified reporting standards currently developed by the European Financial Reporting Advisory group (EFRAG) should become available in the next couple of years. In order to allow banks to also consider these exposures in the assessment of their greenness, the European Banking Authority has developed the so-called Banking book Taxonomy-Alignment Ratio (BTAR), where the use of estimates is allowed. Estimates derived by the present methodology could be used for the calculation of banks' BTAR.

Looking at transition-risk, financial supervisors and central banks in Europe and beyond are paying increasing attention to this dimension, as proved by the publication of a third report on climate risk by the European Systemic Risk Board (ESRB, 2022). With respect to banks, the Banking Supervision arm of the European Central bank has published its first climate stress test on significant institutions (ECB, 2022), while the European Banking Authority has carried out a pilot exercise to investigate how climate risk assessment and classification tools perform (EBA, 2021) and has launched a discussion on the role of environmental risks in the prudential framework (EBA, 2022). The European Insurance and Occupational Pensions Authority (EIOPA) has launched a climate stress test for pension funds, as climate risks are particularly relevant for long-term investors. The European Securities and Markets Authority (ESMA) has started developing a climate risk stress testing framework tailored to the specificities of Central Counterparties (CCPs). In general, there is a growing pressure on financial institutions to identify, measure, manage and monitor climate risk (and broader sustainability risks) in the context of their risk management frameworks. [10]

Finally, it is worth mentioning that the EU sustainable finance framework has adopted the so-called 'double materiality' perspective, meaning that assessing risks stemming from sustainability factors, including climate, is as important as assessing the impacts of businesses on people and the environment. The double materiality perspective will be central in the CSRD, while the SFDR already asks financial market participants to disclose a list of so-called Principal Adverse Impact (PAI) indicators at entity level. For climate, these include the greenhouse-gas intensity of investee companies and the share of investments in companies active in the fossil fuel sector, among others.

[9] In terms of number of firms, SMEs represent 99% of all businesses in the EU. Looking at value added, based on Di Bella et al. (2023), in 2022 SMEs accounted for more than 50% in six 'industrial ecosystems', namely construction (70%), tourism (65%), textiles (64%), proximity, social economy and civil security (60%), retail (59%) and cultural and creative industries (53%).

[10] See European Commission, 'Strategy for Financing the Transition to a Sustainable Economy', COM/2021/390 final.

3 Methodology

Before getting to the issue of assessing the Taxonomy-alignment of financial portfolios, it is worth discussing the broader issue of the availability of data on the environmental performance of financial firms. Let us focus for instance on carbon emissions. Alessi et al. (2021b) analyse listed firms on the STOXX Europe Total Market Index, which covers around 95% of the market capitalization across 17 European countries, and find that only approximately half of the firms report on their scope 1 CO2 emissions. Furthermore, emission data are different across data providers, as sometimes firms do not report on their whole business, so data providers may themselves need to estimate overall emissions, or decide to report the number that is provided even if it does not account for total emissions. It should also be noted that for fossil-fuel firms, including firms in the whole fossil-fuel value chain, the most relevant indicator is scope 3 emissions (accounting in particular for the emissions released in the use of the product). However, scope 3 data is scarce. Moreover, scope 3 accounting is based on internal models and thus figures are poorly comparable across firms. They are also poorly comparable across data providers.[11]

These are examples of measurement problems, which are not uncommon in economics. For instance, GDP statistics, which are so widely used, are themselves considered as an imperfect measure of an underlying concept, i.e. economic growth, as well as inflation can be measured by either changes in a consumer price index, or through a GDP deflator. While we can count on decades of research and progress in the harmonization of economic data, including financial data, we are still at the beginning of a long journey when it comes to environmental data. While these observations apply to aggregate statistics, the problem is even more serious on micro data, which are by their very nature much more prone to errors and omissions. Hence, while it is legitimate to strive for maximum accuracy, we should be aware that there is no such thing as perfect measurement in economics, and even less so in sustainable finance.

In this context, this paper further develops an estimation methodology that can be used for accounting against the EU Taxonomy and in relation to transition risk. In particular, we improve the accuracy of the tool presented in Alessi and Battiston (2022a), which is a top-down estimation methodology. Differently from bottom-up portfolio estimates, which are based on firm-level estimates, this method aims at characterizing the portfolio as a whole. In essence, Alessi and Battiston (2022a) develop Taxonomy-alignment coefficients (TACs) and Transition-risk exposure coefficients (TECs) at the level of economic sectors, using the NACE classification. These coefficients represent the average level of Taxonomy-alignment and exposure to transition risk for a firm active in a given NACE sector.To be precise, they estimate the share of activities in a given sector that comply with SC technical screening criteria, as it is currently not feasible to provide multidimensional estimates considering also the interplay of DNSH and MMS criteria. It should also be noted that Taxonomy activities do not map perfectly onto NACE sectors.

By applying TACs and TECs to all assets in a portfolio, based on the NACE sector where the investee or borrowing firm is active, one can obtain estimates of greenness and transition-risk exposure for the portfolio as a

[11] See Papadopoulos (2022) for a detailed analysis of GHG emissions data across various data providers.

whole. Contrary to firm-level estimates, which are available only for larger firms and based on proprietary models, this estimation methodology is transparent and can be applied to exposures to SMEs.

However, the TACs and TECs developed in Alessi and Battiston (2022a) can be meaningfully applied only to financial assets associated to a counterpart that is based in the EU, as they are derived based on the overall Taxonomy-alignment and transition-risk exposure of the EU economy. Also, they are based on average EU values, while in several sectors there are significant differences in greenness and transition-risk exposure across the various EU Member States. To overcome these limitations, in this paper we extend the set of TACs and TECs to individual countries, including selected non-EU countries.

Considering NACE sectors mentioned in the Taxonomy, we distinguish between two groups of sectors, which we refer to as "ETS sectors" and "non-ETS sectors", as described in the following.

3.1 ETS Sectors

For the manufacturing sectors under the EU ETS framework[12], denoted hereafter as ETS sectors, we develop a novel and specific methodology that derives country level TAC and TEC from the level of emission efficiency and emission intensity of each country in each ETS sector (at the NACE 3 or 4 digit level). These sectors include energy-intensive and/or GHG-intensive activities such as cement or steel manufacturing.

At the EU level, based on the relevant technical screening criteria in the Taxonomy, we estimate that only a share of 5% of these activities is Taxonomy-aligned, while 50% (the bottom half in terms of emission efficiency) is exposed to transition-risk (Alessi and Battiston (2022b)). However, these figures are not based on statistics, rather on the very definitions in the EU Taxonomy.In particular, the EU Taxonomy defines green those installations in a given sector that are more efficient than the average of the top 10% installations in the sector. Hence, assuming a uniform distribution of the emission efficiency of the top 10% installations, this estimate corresponds to 5% at the EU level. However, there could be significant differences across countries depending on where the green plants are located. The Taxonomy also defines the bottom 50% of EU installations by emission efficiency as significantly harmful; however, they are not homogeneously distributed across countries.

We show that it is possible to derive TAC estimates at the country level, which follow from the EU Taxonomy definition at the plant level. Country-TAC need to be proportional to the country-specific emission efficiency levels and, at the same time, respect the overall constraint that their weighted average (by production) equals the TAC at the EU level, i.e. 5% as explained above. In the following, we provide a mathematical derivation of how to determine TAC values with these characteristics.

To proceed with our analysis, it is useful to establish some notations.

- The Taxonomy alignment of an individual plant i, in country c and sector s: $\text{TAC}_{cs}(i)$
- The Taxonomy alignment of sector s in country c: TAC_{cs}

[12] https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets_en

- The emission intensity of a country c in sector s: $\text{INT}_{cs} = \frac{\text{Emissions}_{cs}}{\text{PROD}_{cs}}$
- The emission efficiency of a country c in sector s: $\text{EFF}_{cs} = \frac{\text{PROD}_{cs}}{\text{Emissions}_{cs}}$
- The EU-level production in sector s: PROD_s
- The production of country c in given sector s: PROD_{cs}
- The fraction of EU production in a given country and in a given sector over the total EU of the sector with: $W_{cs} = \frac{\text{PROD}_{cs}}{\text{PROD}_s}$

Based on the Taxonomy technical screening criteria, the appropriate procedure to determine the level of alignment and transition risk for a given country would be to analyse the cumulative distribution of emission efficiency across industrial plants in the country and to determine the probability that they fall in the top 5th percentile and in the bottom 50th percentile. Note that, according to the EU Taxonomy, an individual industrial plant is either aligned or not, based on whether the level of emissions produced per unit of output is above or below the Taxonomy threshold. This implies the following definition.

Definition 3.1 *The alignment of a plant i, in country c and sector s, denoted as $TAC_{cs}(i)$ is a binary variable:*

$$TAC_{cs}(i) = \begin{cases} 1 & \textit{if plant } i \textit{ is aligned} \\ 0 & \textit{else} \end{cases} \tag{1}$$

In the EU, plant emission levels data are available for certain categories but they are not consolidated with production data, so that efficiency values at the plant level cannot be computed. Efficiency can be computed at the country-sector level, i.e. for a given sector in a given country, based on data of production and emissions of the country as a whole in a given sector. It is natural to define TAC at the country level as the expectation of its value at the plant level. This is the expected value of the alignment of a unitary financial investment (1 Euro) into a security of a randomly selected firm in the chosen country-sector c, s.

Definition 3.2 *The Taxonomy-alignment of country c and sector s, denoted as $TAC_{cs}(i)$ is:*

$$TAC_{cs} = \mathbb{E}[TAC_{cs}(i)], \tag{2}$$

where i is randomly chosen from the set of plants in country c and sector s.

If in a given sector the emission efficiency of a country is higher than for another country, we can expect that, on average, there are also higher chances that a randomly chosen plant in that country is Taxonomy-aligned. In turn, this assumption implies that the TAC of a given country-sector is proportional to the country-sector efficiency via a coefficient β_s that is sector specific but is homogeneous across countries. This is stated more formally below.

Assumption 3.1 *Denote the probability that a randomly chosen plant i in country-sector c, s is Taxonomy-aligned as $P_{cs} = P(TAC_{cs}(i) = 1)$. We assume that this is proportional to the emission efficiency of the country c in sector s through a sector-specific coefficient β_s:*

$$P_{cs} = \beta_s \, EFF_{cs} \tag{3}$$

Proposition 3.1 *The values Taxonomy alignment at country level TAC_{cs} are proportional to country efficiency levels*

$$TAC_{cs} = \beta_s \, EFF_{cs}, \tag{4}$$

where the sector-specific coefficient β_s is uniquely determined.

Proof 3.1 *The expected value of the TAC of a plant is also its average on the sample. Then, based on Definition 3.1, we have $\mathbb{E}[TAC_{cs}(i)|\ i \text{ chosen randomly}] = 1 * P_{cs} + 0 * (1 - P_{cs}) = P_{cs}$. Then from Definition 3.2, it follows that $TAC_{cs} = \mathbb{E}[TAC_{cs}(i)] = P_{cs} = \beta \, EFF_{cs}$.*

The EU Taxonomy regulation implies a value of alignment at the EU level. Accordingly, we impose that the weighted average of the TAC_{cs} across countries equals to the EU-level TAC_s for the sector s. As explained above, for ETS sectors this level equals 0.05. We can thus write:

$$\sum_{cs} W_{cs} \, TAC_{cs} = \sum_{cs} W_{cs} \, \beta_s \, EFF_{cs} = \beta_s \sum_{cs} W_{cs} \, EFF_{cs} = TAC_s = 0.05. \tag{5}$$

It follows that:

$$\beta_s = \frac{TAC_s}{\sum_{cs} W_{cs} \, EFF_{cs}} \tag{6}$$

The above derivation yields a unique solution, which ensures that the values of TAC are proportional to the country emission efficiency and that they respect the EU weighted average.

Conversely, for the TEC, we can assume them to be proportional to the country-specific emission intensity levels and impose, at the same time, the constraint that their weighted average (by production) equals the median level at the EU level. The derivation formulas are analogous to the ones above and are omitted here.

In order to compute emission efficiency and intensity, one needs data on emissions (CO2e tonnes) and production (in tonnes) or Gross Value Added (GVA) in Euros. For EU countries, emissions are obtained from Eurostat at the aggregation level of economic sectors that follows the United Nation Common Reporting Format[13] (CRF).

Production and GVA are obtained from Eurostat as part of the PRODCOM system. These data are available at variable levels of granularity (NACE level 3 or 4 digits, more granular for some sectors). After some preliminary

[13] `https://ec.europa.eu/eurostat/databrowser/view/ENV_AIR_GGE/default/table?lang=en`

analysis with GVA, we have opted for production data because the series appear to be more stable over time and are not affected by price variations.

In order to compute emission efficiency and intensity as described above, the quantities at the numerator and the denominator have to be aggregated at comparable sectoral levels. To this end, we have mapped the CRF sectors used for for emissions, onto the NACE sectors used for production. However, it is not straightforward to put together a consolidated dataset of emissions and production for a good number of sectors and EU countries. For 11 NACE codes within the ETS sectors, we have been able to consolidate data from Eurostat for over 10 EU countries. The list is reported in Table 1. We have computed the emission efficiency as ratio production (in tonnes) over emissions (in CO2 tonnes equivalent) and, conversely, the emission intensity as the ratio of emissions (in CO2 tonnes equivalent) over production (in tonnes).

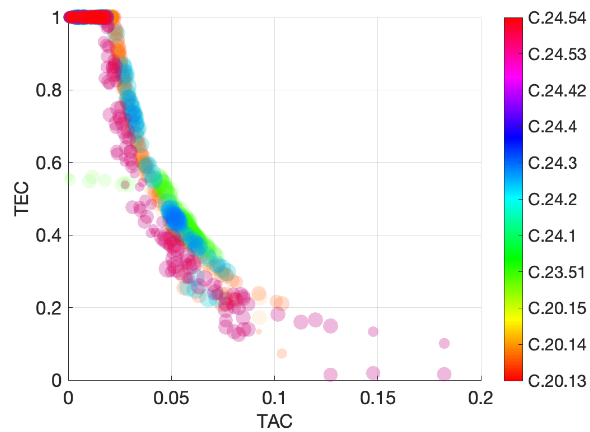
NACE_code	NACE Sector
C.20.13	Manufacture of other inorganic basic chemicals
C.20.14	Manufacture of other organic basic chemicals
C.20.15	Manufacture of fertilisers and nitrogen compounds
C.23.51	Manufacture of cement
C.24.1	Manufacture of basic iron and steel and of ferro-alloys
C.24.2	Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
C.24.31	Cold drawing of bars
C.24.32	Cold rolling of narrow strip
C.24.33	Cold forming or folding
C.24.34	Cold drawing of wire
C.24.42	Aluminium production
C.24.51	Casting of iron
C.24.52	Casting of steel
C.24.53	Casting of light metals
C.24.54	Casting of other non-ferrous metals

Table 1: List of NACE codes for ETS sectors.

To limit the effect of inaccuracy in countries' reportings, we have filtered out levels of production below 1 th. tonnes and levels of intensity that are more than two standard deviations above the mean across countries. By construction, the weighted average of the computed TAC and TEC equals, respectively 0.05 and 0.5. However, the above procedure does not guarantee, alone, that values of TAC and TEC remain bounded within [0 1], so we impose this cap as a final step (it was never necessary for TAC, it was needed for TEC in some cases).

Figure 1 shows a scatter plot of TAC versus TEC values for the set of ETS sectors across EU countries. Each data point represents the value of TAC and TEC for an ETS economic sector in a given country. The scatter plot shows a general tendency whereby the value of TEC grows with the inverse of the value of TAC, which is internally consistent in our framework because country-level TAC are assumed to be proportional to emission efficiency, while TEC are proportional to emission intensity, and emission efficiency and intensity are inversely related.

Figure 1: Scatter plot of TAC values againts TEC values across combinations of economic sectors (NACE codes within the EU ETS system) and EU countries.



3.1.1 ETS sectors for non EU countries

Finally, for non-EU countries we proceeded as follows. In principle, to provide a TAC at country level for a non-EU country, we should compare the distribution of Taxonomy-alignment across plants or issuers in that country, with the distribution within the EU. The TAC for the non-EU country under examination would be adjusted based on whether the distribution in that country is 'shifted' to the right or to the left with respect to the one for the EU. Given that data at plant level and issuer level are not available at this stage neither for EU not for non-EU countries, we resort to the following computation steps and approximations.

1. The distribution of TAC at firm level for firms in the EU countries and in the non-EU country is assumed to be Normal, with different parameters. The procedure that follows can be implemented with any other 2-parameter distribution.

2. The distribution of TAC at firm level for EU firms is proxied by the distribution of TAC across countries.

3. We estimate the mean of the TAC distribution in the non EU country as the average emission intensity in the country for that sector, which is obtained from the available literature and data.

4. As for the variance of the distribution of TAC in the non EU country, we assume that it is proportional to the variance of the distribution in the EU, with the proportionality factor being the ratio between the mean in the country and the mean in the EU. In other words, because the two distributions are, at this stage unknown, we make the simplest assumption: the two distribution have the same "shape" but there is a scaling factor such that if the non EU country TAC has higher mean it will also have proportionally higher standard deviation.

5. Once we have computed the parameters of the TAC distribution in the non EU country, the TAC of the country is computed as the fraction of plants/firms in the non-EU country that do not exceed the EU threshold for emission intensity.

6. The same procedure is carried out for the TEC.

We are of course aware the above procedure is crude and relies on simplistic assumptions. In particular, in reality, the TAC distributions could have fat tails and could have, in general, country specific features. What we present here is best solution we could find to the problem of lack of firm level data, given the objective of estimating at least the order of magnitude of the TAC/TEC.

3.2 Non-ETS Sectors

Also for non-ETS sectors, TAC and TEC are derived considering the criteria for SC to climate mitigation and DNSH to mitigation in the EU Taxonomy. For economic activities not included in the Taxonomy, TECs are derived building on the framework of Climate Policy Relevant Sectors (CPRS, see Battiston et al. (2017)), which allows to identify economic activities highly exposed to transition risk.

We refer to Alessi and Battiston (2022a) for a more detailed description of the rationale and sources of the coefficients. For example, the share of Taxonomy-alignment in the electricity generation sector is estimated as the share of generation from renewable energy sources (biomass, geothermal, hydro, solar, wind). Similarly, the share of transition-exposure in the electricity generation sector is estimated as the share of generation from fossil fuel sources (coal, oil and gas).

To extend the set of TAC and TEC from EU level to individual EU countries, we resort to the statistics that are at the basis of the EU-wide coefficients, mostly from Eurostat. For example, to derive the TAC of the sector NACE H.49.10 (Passenger rail transport, interurban), we have used the ratio of the length of electrified railways over the total length of railways. This number varies across countries and it is available for several EU countries for the years 2011-2019. We estimate the TEC of the same sector as the complement to 1 of the TAC, because it represents the share of non electrified railways (by length).

Table 5 in appendix provides an overview of the underlying rationale for the derivation of TAC and TEC for non-ETS sectors, as well as the data sources used for EU countries. Notice that for many sectors TEC are the complement to 1 of TAC, but this is not always the case. In the example above of electricity generation, the sum of generation from renewable and from fossil do not sum up to one, since nuclear is also to be accounted.

Despite the inclusion of gas and nuclear among Taxonomy-eligible activities, at this stage we do not to consider these sources of power generation for the development of TAC. We actually take a conservative stand and consider gas-powered electricity generation as an activity which is exposed to transition risk. Indeed, the alignment of electricity generation from gas requires the plant to fulfill a number of criteria that are not specific to the technology used (emission intensity) but are specific to the firm and/or the country of operation. As a result, it is not possible to estimate, based on available data, what is the share of gas-based power plant that would be aligned, and of those that risk to become stranded assets. As for nuclear, there are some requirements that apply at country level and that only a handful of EU member States currently fulfil.[14] Within these countries, is currently not possible to estimate the share of existing nuclear facilities fulfilling the plant-level requirements set out in the Taxonomy.

Finally, for non-EU countries, we resort to publicly available statistics comparable to those available for EU Member States. All the details on data sources are available in the Excel tool that accompanies the paper.

Please note that the TAC/TEC coefficients provided in the accompanying tool are the best estimate we could derive at this stage based on publicly available data. Some specific limitations may apply in terms interpretation of the proxy. Notably, effects due to export are not taken into accounts in the recycling of plastic, or the sales of electric cars. This has been highlighted wherever possible in the tool.

4 Data

The analysis is based on yearly data from 2014Q1 to 2023Q1. The main data source is a confidential security-by-security database, namely the Eurosystem's Securities Holding Statistics (SHS) Database - Sector module. The SHS contains information on the holdings of investors aggregated at the level of ESA2010 sectors, and by country. In particular, SHS data cover debt securities, equity instruments and investment fund shares held by investors residing in the Euro Area and several non-Euro Area EU countries (namely Bulgaria, the Czech Republic, Denmark, Hungary, Poland and Romania), as well as non-resident investors' holdings of Euro Area securities that are deposited with a Euro Area custodian. The SHS database covers around 83% of the total outstanding amount of securities issued by Euro Area residents. The SHS database does not contain information on the NACE codes of the issuers. Thus, we associate the NACE code (4 digits) to each issuer on the basis of the ISIN code of the security using Refinitiv EIKON, which is also used as source for price data. Table 2 reports for every period in the data sample, the number of holding records, the number of issuers and ISIN codes, and the total value in nominal terms prior to any further selection. For example, for 2023Q1, the sample comprises about 1.01 million records of holdings of stocks issued by 37710 distinct issuers, corresponding to a total value in market capitalization of 12985 bn Euros. Table 3 reports descriptive statistics of the coverage of the sample after matching issuers with their NACE codes. The coverage in terms of value is higher than the coverage in terms of number of issuers and always above 85%. The coverage of the sample increases over time and is larger than 95% both in terms of issuers and value for 2023 data.

In the analysis we aggregate the monetary values of the holdings along combinations of the following dimensions: 1) ESA2010 sector and country of the holder, 2) ESA2010 sector and country of the issuer, 3) NACE code (4 digits) of the issuer. Finally, to improve the readability of the results, we group the ESA2010 sectors into meta-sectors and exclude from the analysis the sectors that only represent a negligible value of the holdings (see Table 6 in the appendix).

[14]For example, disposal facilities for low-level waste must be operational already, and Member States should have in place a detailed plan to have in operation, by 2050, a disposal facility for high-level radioactive waste.

Period	# holdings	# issuers	# ISIN	Value (bn Euro)
2014Q1	540542	35578	38783	7143
2015Q1	545821	33691	36624	8851
2016Q1	549187	33834	36760	7933
2017Q1	569661	32204	35044	9386
2018Q1	599324	33136	36001	9888
2019Q1	645969	32818	35426	9867
2020Q1	670356	32407	35247	8344
2021Q1	781559	34161	37006	12414
2022Q1	967877	36103	39309	13180
2023Q1	1013630	37710	40718	12985

Table 2: Descriptive statistics of the data set. Columns report for every period the following information: number of holding records (with positive value in Euro); tnumber of issuers identified by the internal organization code (unique); number of ISIN codes (unique); total value of the holdings in nominal terms prior to assigning NACE codes and filtering by country.

Period	% issuers	% value	Value (bn Euro)
2014Q1	79.75%	86.94%	6210
2015Q1	81.47%	88.52%	7835
2016Q1	82.99%	89.61%	7109
2017Q1	84.09%	92.20%	8654
2018Q1	85.69%	92.99%	9194
2019Q1	87.24%	93.54%	9230
2020Q1	88.47%	94.33%	7871
2021Q1	91.12%	94.99%	11792
2022Q1	93.31%	96.52%	12722
2023Q1	95.90%	97.58%	12671

Table 3: Descriptive statistics of NACE codes coverage. Columns report for every period the following information: percentage of issuers for which the NACE code is available (% issuers); percentage of the total value of holdings that is covered (% value); total value of holdings (Value).

5 Results

In this section we apply the country-level TAC and TEC to compute the level of Taxonomy-alignment and transition risk exposure of EU investors' holdings. We use the following definitions.

- **Taxonomy Aligned (TA) holdings** refers to the value of equity holdings that are Taxonomy aligned. For each individual holding of investor i in a given issuer in NACE sector j for the amount X in Euros, the amount that is Taxonomy aligned is $TA_{ij} = X_{ij}\, TAC_j$ where TAC_j is the Taxonomy alignment coefficient for NACE sector j.

- **Transition Exposure (TE) holdings** are defined analogously. The amount that is exposed to transition risk is $TE_{ij} = X_{ij}\, TEC_j$, where TEC_j is the transition risk coefficient for NACE sector j.

In order to compare alignment and exposure of portfolios over time it is useful to separate the effect of changes in the prices of the securities from the effect of changes in the amounts of securities held. The value of TA and TE holdings *in real terms* are defined as follows:

$$\mathrm{TA}_{ij}(t) = X_{ij}(t)\frac{P_j(t_b)}{P_j(t)}\,\mathrm{TAC}_j \tag{7}$$

$$\mathrm{TE}_{ij}(t) = X_{ij}(t)\frac{P_j(t_b)}{P_j(t)}\,\mathrm{TEC}_j. \tag{8}$$

In the expression above, t_b represent the base year, t the current year and P_j the price of one unit of security of issuer j. For instance, with $t_b = 2023$, for a given year t, $TA_{ij}(t)$ represents the value of the holding in 2023 prices. Changes over time should be interpreted as changes in the value of the holding as if prices were those of 2023. We then aggregate over issuers to obtain the amount of TA holdings for a given investor

$$\mathrm{TA}_i(t) = \sum_j X_{ij}(t)\frac{P_j(t_b)}{P_j(t)}\,\mathrm{TAC}_j \tag{9}$$

$$\mathrm{TE}_i(t) = \sum_j X_{ij}(t)\frac{P_j(t_b)}{P_j(t)}\,\mathrm{TEC}_j. \tag{10}$$

5.1 Evolution of TA and TE holdings over time

As an illustration of the type of questions that our methodology can address, we first focus on the question whether TA and TE holdings have changed in the recent years, and whether we can detect any particular trends. To this end, we examine the evolution over time of TA and TE holdings in real terms (i.e. expressed in 2023 prices).

At the most aggregate level, Table 4 reports for every period in the data sample, the number of combinations of holder countries and sectors, the value of holdings and the value of TA and TE holdings also in percentage of total. Monetary values are expressed in real terms unless indicated otherwise (i.e. "nominal"). The real term value is computed at the individual security level using the last available price (mostly 2023, unless the firm has defaulted or the ISIN code is not held by any holder in the sample) and then aggregated. The total value of the holdings increased from 6556 to 9068 bn Euro from 2014 to 2023. TA grew slightly from 254 bn to 303 bn Euro, while TE increased from 850 bn to 1100 bn Euro. However, in percentage of total holdings, TA and TE holdings decreased slightly from 3.88% to 3.34% and from 12.97% to 12.13%, respectively. It is out of the scope of the present analysis to examine if this decrease is significant and what is its origin. However, we observe that the NACE coverage improves over the period, hence the trend does not seem to be due to data quality issues.

As TA and TE estimates are based on the economic sector of the issuer, the trend observed in the data would be consistent with the hypothesis that holders have a tendency to invest a growing part of their portfolios in NACE sectors characterized by zero TAC and TEC, and a decreasing share of their portfolios into real economy sector characterized by larger TAC and TEC[15]. To investigate whether this is the case, Table 7 in the appendix shows

[15]Note that if investors tend to invest over time larger fraction of their portfolios into securities issued by financial firms, then the TA share and TE share can both decrease. The fact that TA share decrease does not mean the the TE share has to increase. Indeed, at the portfolio level both can increase or decrease or any combination, depending on the set of sectors on which the investor put more weight.

the evolution of the share of aggregate holdings in each NACE sector over time. The percentage of holdings in NACE sector K (Finance) has almost doubled over the considered time span. The financial sector has TAC and TEC equal to 0, as no technical screening criteria exist in the Taxonomy for financial activities as such for climate change mitigation (see Section 3). Hence, investments in equity funds or in any financial entity do not contribute to TA and TE, although a financial institution holds a portfolio of investments in companies, some of which operate in the real economy and have non-zero TAC and TEC. In any case, we are unable to unpack the holdings of financial intermediaries and need to stick to the Taxonomy approach, whereby financial activities are not Taxonomy-eligible. The percentage of holdings in NACE sector J (Information and communication) has almost tripled from 2014 to 2023. While the Taxonomy does include two activities related to this NACE sector, its TAC and TEC are zero. Finally, holdings in manufacturing companies (NACE sector C) decreased from 72% to 45%. While NACE sector C is very large and comprises many subsectors with zero TAC and TEC, it also includes some of the sectors with a non-zero TAC and a relatively large TEC of 0.5.

	Value (nom.)	Value	TA	TE	TA	TE
Period	bnEUR	bn EUR	(bn EUR)	(bn EUR)	(% of Value)	(% of Value)
2014Q1	4283	6556	254	850	3.88%	12.97%
2015Q1	5366	7065	244	901	3.45%	12.76%
2016Q1	4839	7182	255	978	3.54%	13.62%
2017Q1	5839	7529	286	978	3.80%	12.99%
2018Q1	6154	7500	285	978	3.80%	13.03%
2019Q1	6452	7863	294	983	3.74%	12.51%
2020Q1	5524	7960	304	1013	3.82%	12.73%
2021Q1	8433	8473	282	1031	3.32%	12.16%
2022Q1	9318	8932	287	1065	3.21%	11.93%
2023Q1	9068	9068	303	1100	3.34%	12.13%

Table 4: Aggregate holdings over time. Columns report for every period: value of holdings in bn Euro; value of TA and TE holdings in bn Euro and in percentage of total. Values in Euro are in real terms unless specified otherwise (nominal).

The area plot in Figure 2 shows the evolution of TA and TE holdings in monetary value (in real terms) by holder sector, while the area plot in Figure 3 shows the evolution of TA and TE holdings as percentage of total holdings, with the breakdown by holder sector. Throughout the sample, “NFCs”, “Investment funds”, and “Households and No profit institutions” have the largest volumes of TA holdings. Looking at transition risk, it is noteworthy the increase of OFI’s TE holdings (in fuchsia), which over time becomes comparable to TE holdings of households and no profit institutions (in green). As percentage of overall TE holdings, OFI’s TE holdings increased by more than three times from 5.5% of total TE in 2014 to 18.3% in 2023 (see Table 9 in the appendix). As we do not observe a generalized in crease in TE holdings across sectors, nor across financial institutions, this finding is consistent with the hypothesis that transition risk might be shifting to less regulated parts of the financial system. This result is in line with Alessi et al. (2021a), who show that after the Paris Agreement, European investors reduced their participation in high-carbon companies at the aggregate level, but OFIs increased it.

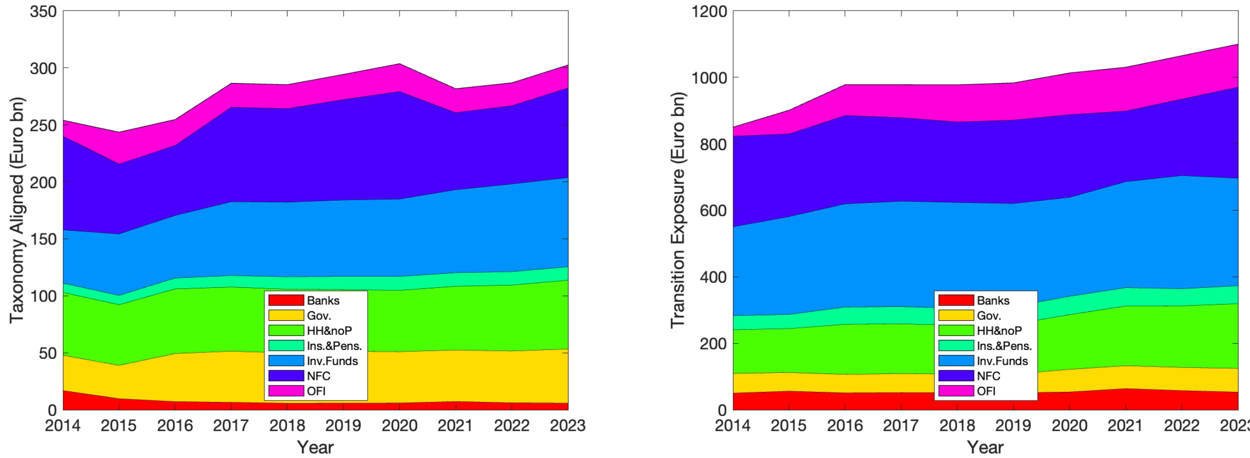


Figure 2: Evolution over time of TA (left) and TE (right) holdings in monetary values

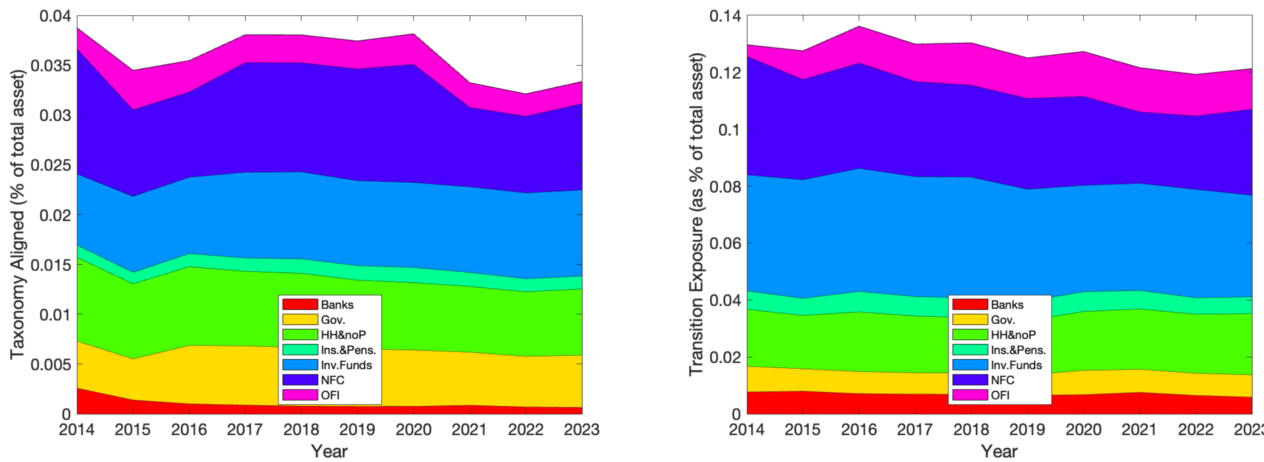


Figure 3: Evolution over time of TA (left) and TE (right) holdings as percentage of total holdings across EU investors.

We complement the previous results with the study of the evolution over time of the TA and TE shares with reference to the total holdings of a given sector, as opposed to total holdings across sectors. In other words, we look at the % of Taxonomy alignment and Transition-risk exposure of each sector defined as the ratio of TA or TE holdings over the value of the holdings of the sector. As shown in the left panel of Figure 4, TA holdings as percentage of the portfolio value by holder sector is generally below 6% and at about 3% on average. However, the Government sector exhibits an exceptionally large share of TA compared to the other sectors, exceeding 17% in some years. This might be due to Governments' holdings into energy and utility companies, active in NACE sectors which are among those with the highest TAC. TA shares remain relatively stable over time, with some exceptions. In particular, as shown in Table 10 in the appendix, banks' TA share more than halves from 4.4% to 2.1% from 2014 to 2023. Looking at the right panel of Figure 4, the TE portfolio share is for all sectors higher than the TA share, and about 11% on average. The Government sector is associated the largest portfolio TE share, probably again owing to its holdings in NACE sectors linked to energy, which not only have among the highest TACs but also fairly large TECs (and particularly large in some countries). OFIs exhibit the largest variation in the TE share of their portfolio, which was at 5.5% in 2014, peaked to almost 24% in 2020 and is now at around 20%, again pointing towards a tendency of less regulated financial institutions to invest in sectors characterized by high TEC and low or zero TAC, such as those exclusively linked to fossil fuels.

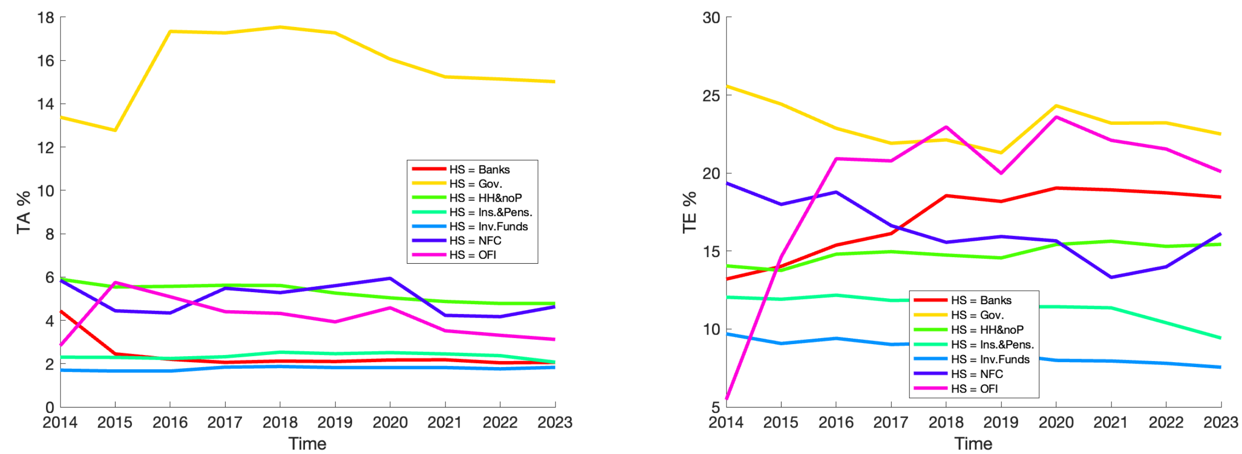


Figure 4: Left: Evolution over time of TA portfolio shares by investor class. Right: Evolution over time of TE portfolio shares by investor class.

5.2 TA and TE levels of holder sectors: cross country heterogeneity

Next, we address the question of the heterogeneity across countries of TA and TE portfolio shares for the various types of holders. To this end, the box plots in Figure 5 represent for each holder sector the interquartile range (IQR) and the median of TA portfolio shares across countries.

In several cases the values of the IQR (i.e. the length of box) are comparable or larger than the value of the median (the red bar), indicating a large dispersion of the values across countries. For instance, looking at TA (left panel), Gov is the sector with the largest IQR while InvFund is one with the smallest IQR. While they have a comparable median, the IQR of the first is about 7 times larger than the one of the second. The comparison is even starker for TE (right panel, note the different scale of the two charts). This indicates a much larger dispersion in TE portfolio shares across Governments of different EU countries, compared to investment funds and other investor classes across EU countries. One possible explanation is that Governments tend to have a less diversified portfolio of holdings than, e.g., financial institutions. In particular, some governments may have large stakes in domestic energy companies with low TAC, while othergovernments may have large stakes in domestic utilities companies with relatively high TAC. Similar considerations hold for non-financial corporations, which tend to have a strong domestic component in their holdings.

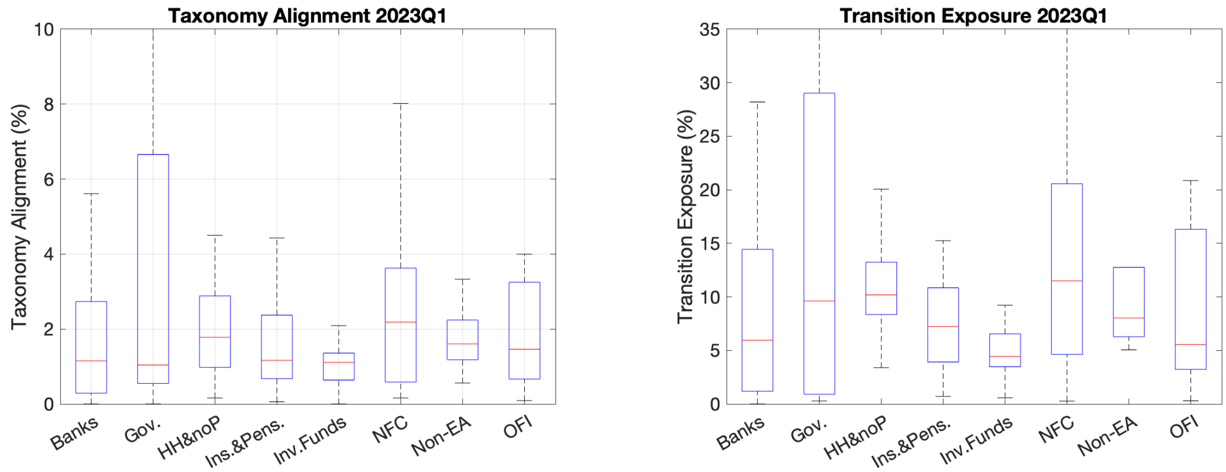


Figure 5: Box plots representing for each investor class the interquartile range (IQR) and the mean of TA portfolio shares (left panel) and TE portfolio shares (right panel) across countries of the holder sector in 2023Q1. Note the different scale of the two charts.

The tool to compute TA and TE across sectors and countries makes it tempting to compile a ranking of virtuous countries. Caveats should be highlighted before proceeding to such an exercise. Notably, levels can vary across countries upon the following factors:

- TA can be high in certain economic sectors, such as electricity, utility and railways. Holder sectors with, relatively speaking, larger shares in these sectors will have, ceteris paribus, higher TA. However, this could reflect institutional factors rather than incentives or decisions to green their investments.
- Similarly, TE can be large in sectors of primary energy (e.g. the oil & gas value chain) and energy-intensive manufacturing (e.g. cement and iron & steel), for which the concentration of exposure could again reflect national specialization or institutional factors.

For less diversified holder sector/countries, with investments concentrated in particular economic sectors or even individual companies, the above phenomena can lead to particularly high levels of TA and/or TE. A deep dive in an example can be useful to understand the caveats. In 2021Q1, the sector Non-financial investors (S_16) of PT had a portfolio weight of 89.4% on a company classified as utility electricity transmission (hence with TAC = 1), plus some additional smaller weights on companies classified as railways and utility electricity, totaling a TA of 92%. In other periods, the weights over these companies vary, but the overall TA of this country-holder sector remains very high on average. While this sector represents a small portion of holdings across holders in PT, when we rank holder sectors in different countries we need to keep in mind that in some countries, some holder sectors may be less diversified that in other countries.

5.3 Country-level TAC and TEC vs EU-level TAC and TEC

Finally, as a robustness check, we compare the results described above with those we obtain by applying EU-level coefficients as in Alessi and Battiston (2022a), as opposed to the country-level coefficients developed in this study. Figure 7 in the appendix plots the estimates of TA portfolio shares (left panel) and TE portfolio shares (right panel) for the various investor classes at the aggregate EU level, based on EU-level TAC and TEC (orange bars) and country-level TAC and TEC (mycol bars). The differences between the two sets of estimates are relatively small, i.e. in the order of a half a percentage point for TA, and around 4 p.p. for TE, on average. This is, on the one hand, reassuring, as the two approaches do not yield different messages overall while looking at aggregate exposures at EU level. On the other hand, discrepancies between the two sets of estimates indicate that there is indeed value in using country-level coefficients, as the estimates are not exactly the same, and are necessarily more precise.

Figure 1 in the appendix looks at differences between the two approaches at a higher level of disaggregation. Each dot in the scatter plots represents a combination of a holder sector, a country and a period. The position of the dot in the quadrant depends on the value of the estimate obtained by using EU-level coefficients (x-axis) and country-level coefficients (y-axis). For those combinations of country-sectors and periods on the 45 degree line, it makes no difference to adopt one approach or the other. However, there are a large number of dots that are not on the 45-degree line, and some are actually quite far from it. Therefore, even if at the aggregate EU level it may not make a big difference to use one approach or the other, there are several cases in which country-level coefficients are clearly preferred.

6 Conclusions and further research

The main contribution of this paper is to extend at the country level the methodology previously developed in Alessi and Battiston (2022a), which estimates on the one hand the level of Taxonomy-alignment of financial institutions' investments and, on the other hand, their exposure of climate-related transition risk. The goal of this methodology is to overcome the problem of limited availability of data for many counterparties of financial institutions, which makes it difficult or impossible to estimate the Taxonomy-alignment and the transition risk of the portfolio as a whole. While the coefficients (TAC and TEC) proposed in Alessi and Battiston (2022a) are estimated on the basis of EU-level statistics, here we develop country-specific coefficients for individual EU Member States and non-EU countries. This extension is crucial to enhance the precision of the estimates. Indeed, TAC and TEC at country level may largely differ from those at EU level. For instance, in the sector of electricity generation, the level of reliance on renewable vs. fossil sources varies substantially across countries. As a result, country-level TAC and TEC bring higher granularity in the estimation.

We apply the methodology to a confidential dataset covering equity and bond holdings for investors located in

EU27 from 2014 to 2023. In the aggregate, no marked trends are observable. However, some changes over time become visible for specific holder sectors, in particular a substantial increase in the exposure to transition risk of less regulated financial institutions. Looking at cross-country heterogeneity, our results indicate a large dispersion of Taxonomy-alignment and transition-risk exposure across countries, in particular for some investor classes.

Our estimates of Taxonomy-alignment and transition-risk exposure for individual investor classes can be used by supervisors as benchmark levels for each sector and country, against which the performance of individual financial institutions can be assessed. From a macro(prudential) perspective, our estimates provide information on where the market stands in terms of greenness and risk exposure. This information can be used, for instance, to identify clusters of country/sectors with similar values of alignment and exposure. It should also be stressed that the methodology developed in this paper does not need confidential or supervisory data, as it can be applied to any portfolio of holdings. As such, it can be used by a financial institution to assess its own exposures, as well as on publicly available data.

Looking at Taxonomy-alignment in particular, given the particular features of the relevant regulatory environment, a perfect measure of the overall Taxonomy-alignment of financial institutions will not be available in the foreseeable future. However, our methodology can be used already now to assess how green individual financial institutions and the financial system as a whole are, considering their SME and non-EU exposures too. This information is needed to financial supervisors, as an increase in the Taxonomy alignment of a financial institution can be seen as a mitigating measure towards environmental risks the institution may be exposed to. For the same reason, it is a crucial piece of information for macroprudential supervisors, who are in charge of monitoring risks to the financial system as a whole. Estimates of Taxonomy-alignment are essential not only to policymakers, but also to financial institutions themselves, as they need to design their transition plans and deserve their transition efforts to be recognized against measurable performance indicators. To this aim, financial institutions can use the present methodology for voluntary disclosures and whenever the regulation allows the use of estimates. Finally, this is an information that the market is asking for, to be able to make informed investment decisions.

Turning to climate-related transition risk, reliable scenarios and stress-testing exercises can only be based on a reliable assessment of financial institutions' exposures. Since a legal definition, or Taxonomy, of harmful activities is lacking, for the time being such assessment can only be based on estimates and proxies. Scenarios and stress-testing exercises also need to be carried out at some level of aggregation, since firm-level information is not only often unavailable, but would also be difficult to process in the context of large-scale exercises. However, to increase the reliability of the results, modellers should try to reflect the 'transition discussion' in their analysis. In other words, not only no company is 'doomed' owing to the low-carbon transition, but only very few and well-defined economic activities are entirely exposed to transition risk, e.g. coal mining. Indeed, even within sectors characterized by high carbon emissions, such as e.g. transport, some manufacturing activities, and buildings, companies can not only improve their environmental performance and reduce their exposure to transition risk, but even become fully green.

In fact, these are precisely the sectors with the highest greening potential. As a consequence, it would be a mistake to consider these entire sectors as equally exposed to transition risk, just because they are generally characterized by high emissions. The approach we propose reflects the different degrees of riskiness of the various economic sectors, overcoming the binary approach whereby sectors are either risky or not risky. By doing so, our methodology avoids sending the wrong message to investors stemming from to the stigmatization of entire economic sectors. Finally, it should be noted that a financial institution's exposure to harmful activities is also a measure of its negative impact. Hence, the transition-risk exposure estimates presented in this paper could be included among PAI indicators in the context of the SFDR, with the caveat that the TEC methodology takes a static look at exposure to harmful activities, while the actual exposure to transition risk of financial institutions is also dependent on the 'direction of travel' of the counterparts they finance.

Further work could look into the following directions. First, one could try to compare the country-level estimates obtained with our methodology with bottom-up estimates obtained from firm-level and plant level data. This comparison was not done here because we did not have access to such data at this stage. For some of the ETS sectors (e.g. cement and steel) GHG emissions data repository exist at plant level, but they do not provide also production volumes, so that emission intensity data is in general not available. More generally, plant level data and intra-firm data would be needed to associate more precise TACs and TECs to firms which have installations and business lines in different countries with different TACs and TECs. Note that Eurostat provides the emission data aggregated at the sector level required by the UNFCC reporting framework. Eurostat (Prodcom) provides also production volumes at NACE codes (4 digits at sometimes beyond). However, the firm-level data from which the sector level are aggregated is not available. Presumably there could be competition issues (volumes at firm level are regarded as strategic information) that induce firms to require the confidentiality of this data. However, emission intensity data is key for the implementation of the Taxonomy. Given the societal importance of data on emission efficiency, a more balanced tradeoff could be struck between individual and public interest in this regard.

Second, in this study we rely on the country-level data of production and emission levels from Eurostat. One issue we faced is that we observe variations in efficiency for a given country over the years, which are hard to explain in terms of variation in efficiency of the technology and could be explained in terms of changes in the reporting. To our knowledge, these numbers are the only official numbers from which efficiency and intensity can be computed at the country level. Therefore, it is important to better understand the origin of these variations, possibly by comparing them with alternative intensity estimates in the cases where they exist.

Finally, the methodology developed here and the coefficients which we make available to the community of academics and practitioners could be useful for an emerging stream of work on the impact of climate policies on investors' holdings (Alessi et al., 2021a; Boermans and Galema, 2019; Reghezza et al., 2021; Benz et al., 2020). The extension of the methodology to the other Taxonomy objectives would be useful as the Taxonomy gets further developed; however, it presents serious challenges owing to the very loose mapping of Taxonomy activities into

NACE sectors for environmental objectives beyond climate change mitigation.

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A Description of TAC and TEC for non-ETS sectors

NACE code	NACE description	TAC proxy	TEC proxy
C.20.16	Manufacture of plastics in primary forms	Ratio [Recycled Plastic waste]/[Recycled Total waste] in %. For EU level we used share of recycled plastics demand in EU (6%), not available at country level. Data source Eurostat, code ENV_WASTRT.	1 - TAC
C.29.1	Manufacture of motor vehicles	Ratio of registered battery electric vehicle (hybrid plug-in cars do not qualify and are not taken into account). Datasource: EEA.	1 - TAC
C.30.2	Manufacture of railway locomotives and rolling stock	Ratio [Electrified length of lines in km] / [Total length of lines in km] in %. This variable is the same used for the study TAC EU2020. Datasource: Eurostat, code: RAIL_IF_LINE_NA	Proxy: 1-TAC, because railways locomotives that are not electric are ICE.
D.35.11	Production of electricity	Ratio [Total gross electricity production from renewable sources] / [Gross electricity production in Gwh] in %. Datasource: Eurostat, code NRG_BAL_PEH	Ratio [Total gross electricity production from fossil sources] / [Gross electricity production in Gwh] in %. Datasource: Eurostat, code NRG_BAL_PEH
D.35.21	Manufacture of gas	Data for biogas production as share of total gas production is not available on eurostat (only biofuel). At this stage we set this TAC as not available (N.A.) Data: eurostat, code: nrg_te_bio	1 because data for biogas not available.
D.35.3	Steam and air conditioning supply	Ratio of renewable energy sources in heating and cooling. Datasource Eurostat, code nrg_ind_ren.	Ratio of fossil energy sources in heating and cooling. Datasource Eurostat, code nrg_ind_ren.
E.38.11	Collection of non-hazardous waste	Ratio [Treatment of hazardous and non-hazardousness recycled waste]/[Generation of hazardousness and non-hazardousness total Waste]. Data source: Eurostat, code ENV_WASTRT	This NACE sector does not belong to the list of sectors defined as highly exposed to transition risk.

Continued on next page

Table 5 – *Continued from previous page*

NACE code	NACE description	TAC proxy	TEC proxy
E.38.21	Treatment and disposal of non-hazardous waste	Indicator: [Biowaste]/[Total waste] * [%effectively recycled waste]. Total waste = Generation of total waste; Biowaste = Animal and food waste; % effectively recycled = % of recycled waste at a country level used for E.38.11. Datasource: Eurostat, code ENV_WASGEN	This NACE sector does not belong to the list of sectors defined as highly exposed to transition risk.
F.42.13	Construction of bridges and tunnels	Ratio [total length of electrified railways]/total length of roads and railways]. Data source Eurostat, code (railways) RAIL_IF_TRACKS, roads ROAD_IF_ROADSC	Proxy: 1-TAC.
F.43.22	Plumbing, heat and air-conditioning installation	Ratio of electricity and heat generation from renewable sources out of total. Data source: Eurostat, code NRG_BAL_C	Proxy: 1-TAC.
NACE code	NACE description	TAC proxy	TEC proxy
H.49.10	Passenger rail transport, interurban	Ratio: [Electrified railway lines km / Total km]. Datasource Eurostat, code RAIL_IF_TRACKS	Proxy: 1-TAC.
H.49.20	Freight rail transport	Ratio: [Electrified railway lines km / Total km]. Datasource Eurostat, code RAIL_IF_TRACKS	Proxy: 1-TAC.
H.49.31	Urban and suburban passenger land transport	Ratio: [Num. Electricity Buses]/[Num Total Buses] in %. Data source: Eurostat, code: ROAD_EQS_BUSMOT.	Proxy: 1-TAC.
H.49.32	Taxi operation	Ratio of registered battery electric vehicle (hybrid plug-in cars do not qualify and are not taken into account). Datasource: EEA.	Proxy: 1-TAC.
H.49.39	Other passenger land transport n.e.c.	Ratio: [Num. Electricity Buses]/[Num Total Buses] in %. Data source: Eurostat, code: ROAD_EQS_BUSMOT.	Proxy: 1-TAC.

Continued on next page

Table 5 – *Continued from previous page*

NACE code	NACE description	TAC proxy	TEC proxy
H.49.41	Freight transport by road	Ratio: [n. of Electric Lorries] / [Total n. of Lorries]. Datasource: Eurostat, code: ROAD_EQS_LORMOT	Proxy: 1-TAC.
H.52.21	Service activities incidental to land transportation	Ratio: [n. of Electric Lorries] / [Total n. of Lorries]. Datasource: Eurostat, code: ROAD_EQS_LORMOT	Proxy: 1-TAC.
H.53.1	Postal activities under universal service obligation	Ratio: [n. of Electric Lorries] / [Total n. of Lorries]. Datasource: Eurostat, code: ROAD_EQS_LORMOT	Proxy: 1-TAC.
H.53.2	Other postal and courier activities	Ratio: [n. of Electric Lorries] / [Total n. of Lorries]. Datasource: Eurostat, code: ROAD_EQS_LORMOT	Proxy: 1-TAC.
N.77.11	Renting and leasing of cars and light motor vehicles	Ratio of registered battery electric vehicle (hybrid plug-in cars do not qualify and are not taken into account). Datasource: EEA.	Proxy: 1-TAC.
N.77.12	Renting and leasing of trucks	Ratio: [n. of Electric Lorries] / [Total n. of Lorries]. Datasource: Eurostat, code: ROAD_EQS_LORMOT	Proxy: 1-TAC.

Table 5: List (part 1) of NACE codes for non-ETS sectors. Columns 3 and 4 report concise explanation of the proxy used to compute TAC and TEC at country level. More details, including data sources for non-EU countries, are available in the accompanying tool.

B Aggregation and selection of ESA2010 holder sectors

HS Code	Description	HS Name	Filter
U	Unallocated	Unallocated	0
S_11	Non-financial corporations	NFC	1
S_121	Central Banks	Central Banks	1
S_122	Deposit taking corporations except central banks	Banks	1
S_123	Money market funds (MMF)	MMF	0
S_124	Non-MMF Investment funds	Inv.Funds	1
S_125W	Other financial corporations1 excluding financial vehicle corporations	OFI	1
S_125A	Financial vehicle corporations	OFI	1
S_128	Insurance corporations	Ins.&Pens.	1
S_129	Pension funds	Ins.&Pens.	1
S_12KU	Monetary financial institutions (sub-sector not identified)	Monetary financial inst.	0
S_12QU	Other insurance corporations and pension funds (sub-sector not identified) (transitional period)	Ins.&Pens.	1
S_1311	Central government (voluntary breakdown)	Gov.	1
S_1312	State government (voluntary breakdown)	Gov.	1
S_1313	Local government (voluntary breakdown)	Gov.	1
S_1314	Social security funds (voluntary breakdown)	Gov.	1
S_13U	Other General Government (sub-sector not identified)	Gov.	1
S_14	Households excluding non-profit institutions serving households (voluntary breakdown (for resident investors); mandatory if third party holdings)	HH&noP	1
S_15	Non-profit institutions serving households (voluntary breakdown)	HH&noP	1
S_1MU	Other households and non-profit institutions serving households (sub-sector not identified)	HH&noP	1
S_16	Non-financial investors excluding households (to be reported if third party holdings)	Other non-FInv	0
S_1KK	Central banks and general government (to be reported only for holdings by non-euro area countries)	Non-EA	0
S_1KL	Investors other than central banks and general government (to be reported only for holdings by non-euro area countries)	Non-EA	0

Table 6: Holder sectors codes and legend. The table reports the following information. The holder sector (HS) code identifies sectors according to the ESA2010 classification. The description of the sector is the textual description from the SHS documentation. HS name is the name used in the legends. Filter=1 identifies the sectors used in the analysis. Several HS codes are intentionally aggregated under the same HS name for readability of the charts.

C Holdings by issuer's NACE sector

NACE	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
A	0.04	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
B	0.75	1.16	1.53	1.66	1.62	1.67	1.59	1.60	1.87	1.73
C	72.24	59.64	43.45	44.46	45.25	47.91	45.44	46.72	45.24	45.47
D	2.36	2.83	4.71	5.31	5.35	5.22	5.54	5.06	5.24	5.27
E	0.20	0.26	0.42	0.42	0.46	0.45	0.50	0.52	0.50	0.48
F	0.91	1.13	1.83	1.73	1.80	1.69	1.75	1.86	1.77	1.70
G	1.80	3.15	4.96	5.28	5.27	4.79	5.01	5.06	5.17	5.54
H	1.02	1.44	2.65	2.66	2.65	2.48	2.58	2.70	2.74	2.62
I	0.25	0.33	0.51	0.55	0.58	0.60	0.59	0.61	0.65	0.66
J	5.05	7.15	10.97	11.26	10.91	10.72	11.76	11.48	13.22	14.52
K	7.94	9.16	14.71	14.77	14.85	13.94	14.42	13.86	14.25	13.72
L	0.75	1.06	1.79	1.79	1.88	1.73	2.00	1.95	2.06	2.06
M	0.79	1.04	1.76	1.62	1.66	1.58	1.69	1.78	1.91	1.91
N	5.67	11.25	10.05	7.79	6.98	6.41	6.23	5.69	4.22	3.16
O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P	0.01	0.01	0.01	0.01	0.01	0.02	0.03	0.03	0.03	0.04
Q	0.14	0.23	0.37	0.39	0.40	0.45	0.46	0.45	0.47	0.46
R	0.06	0.10	0.19	0.21	0.21	0.21	0.28	0.52	0.53	0.54
S	0.01	0.04	0.05	0.06	0.06	0.06	0.07	0.06	0.06	0.06
U	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grand Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 7: Evolution of the value of holdings in each NACE sector (main section) as percentage of total holdings in the full dataset

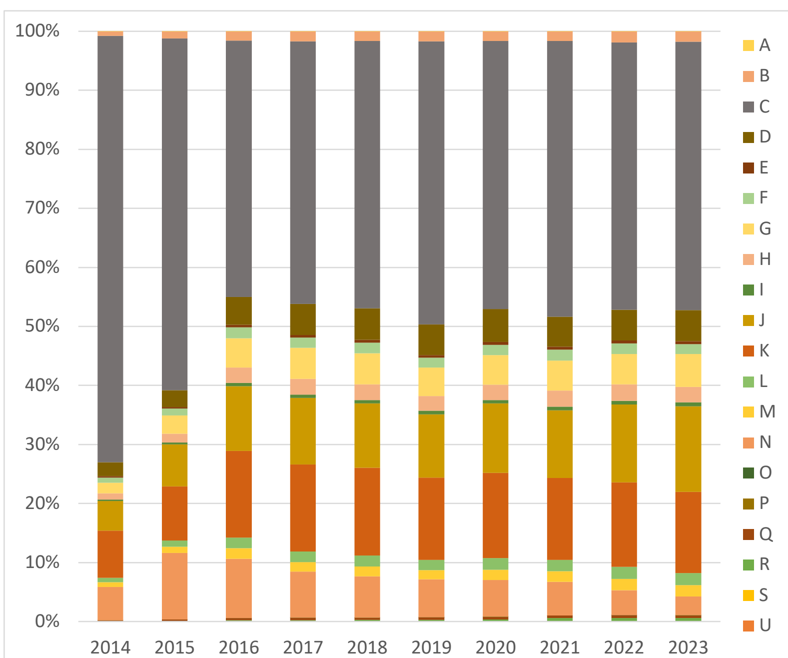

Figure 6: Area plot (stacked) showing the evolution of the value of holdings in each NACE sector (main section) as percentage of total holdings in the full dataset.

D TA and TE - contribution by holder sector

Holder sector	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Banks	6.7	4.1	2.9	2.3	2.1	2.0	2.0	2.6	2.2	2.0
Gov.	12.2	12.0	16.6	15.6	15.5	15.4	14.8	16.0	15.8	15.7
HH&noP	21.7	21.8	22.3	19.7	19.6	18.4	17.7	19.8	20.1	19.9
Ins.&Pens.	3.2	3.4	3.7	3.5	3.8	3.9	4.0	4.2	4.1	3.9
Inv.Funds	18.4	22.1	21.6	22.6	23.0	22.8	22.4	25.8	26.8	25.9
NFC	32.4	25.2	24.1	28.9	28.8	29.9	31.1	24.0	23.9	26.0
OFI	5.4	11.5	8.9	7.3	7.3	7.5	8.0	7.4	7.0	6.6
Grand Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 8: Evolution of TA holdings by holder sector as percentage of total across sectors.

Holder sector	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Banks	13.3	13.3	13.5	14.5	16.1	16.6	16.2	16.8	16.9	16.8
Gov.	25.7	23.1	20.0	19.7	19.3	19.4	20.7	20.6	20.9	20.5
HH&noP	14.1	13.0	12.9	13.4	12.8	13.3	13.1	13.9	13.8	14.1
Ins.&Pens.	12.1	11.3	10.6	10.6	10.3	10.4	9.7	10.1	9.4	8.6
Inv.Funds	9.7	8.6	8.2	8.1	7.9	7.7	6.8	7.1	7.0	6.9
NFC	19.5	17.0	16.4	14.9	13.5	14.5	13.3	11.8	12.6	14.7
OFI	5.5	13.8	18.3	18.7	20.0	18.2	20.1	19.6	19.4	18.3
Grand Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 9: Evolution of TE holdings by holder sector as percentage of total across sectors.

E TA and TE shares by holder sector

Holder sector	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Banks	4.4	2.5	2.2	2.1	2.1	2.1	2.2	2.2	2.0	2.1
Gov.	13.4	12.8	17.3	17.3	17.5	17.3	16.1	15.2	15.1	15.0
HH&noP	5.9	5.5	5.6	5.6	5.6	5.3	5.0	4.9	4.8	4.8
Ins.&Pens.	2.3	2.3	2.2	2.3	2.5	2.5	2.5	2.5	2.4	2.1
Inv.Funds	1.7	1.7	1.7	1.8	1.9	1.8	1.8	1.8	1.8	1.8
NFC	5.9	4.4	4.3	5.5	5.3	5.6	5.9	4.2	4.2	4.6
OFI	2.8	5.8	5.1	4.4	4.3	3.9	4.6	3.5	3.3	3.1

Table 10: Evolution of TA share. i.e. fraction of TA holdings over holdings of each holder sector.

Holder sector	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Banks	13.2	14.0	15.4	16.1	18.6	18.2	19.0	18.9	18.7	18.5
Gov.	25.6	24.4	22.9	21.9	22.1	21.3	24.3	23.2	23.2	22.5
HH&noP	14.1	13.8	14.8	15.0	14.7	14.6	15.4	15.6	15.3	15.4
Ins.&Pens.	12.0	11.9	12.2	11.8	11.9	11.4	11.4	11.4	10.4	9.4
Inv.Funds	9.7	9.1	9.4	9.0	9.1	8.4	8.0	8.0	7.8	7.6
NFC	19.4	18.0	18.8	16.6	15.6	15.9	15.7	13.3	14.0	16.1
OFI	5.5	14.6	20.9	20.8	23.0	20.0	23.6	22.1	21.5	20.1

Table 11: Evolution of TE share. i.e. fraction of TE holdings over holdings of each holder sector.

F Country-level vs EU level TAC and TEC

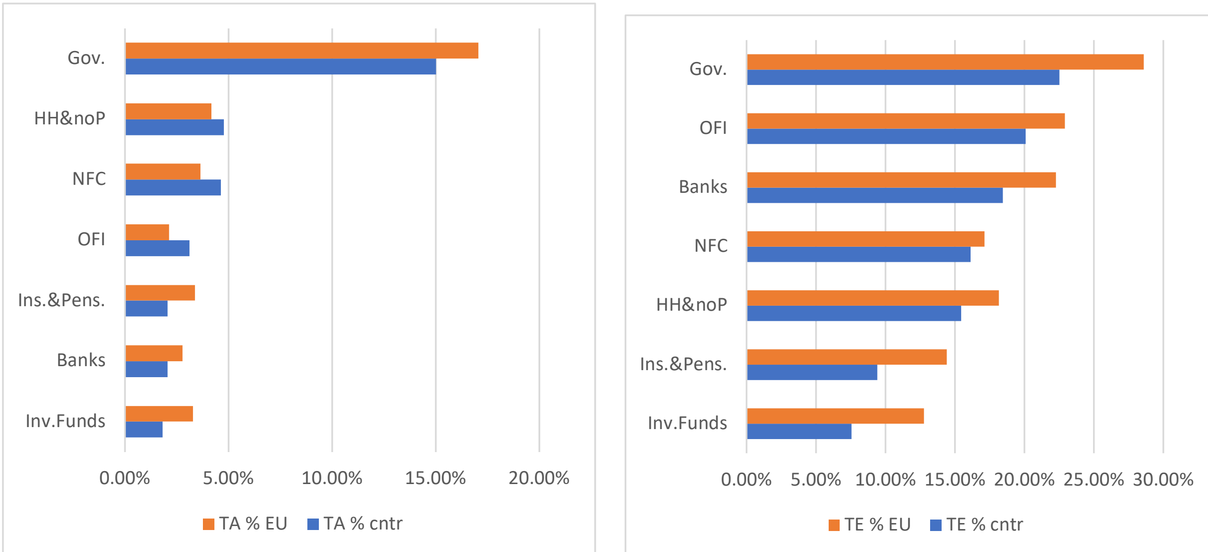

Figure 7: Portfolio TA share (left) and TE share (right) across holder sectors, comparing estimates using country-level TAC, TEC (mycol bars) and EU-level TAC, TEC (orange bars).

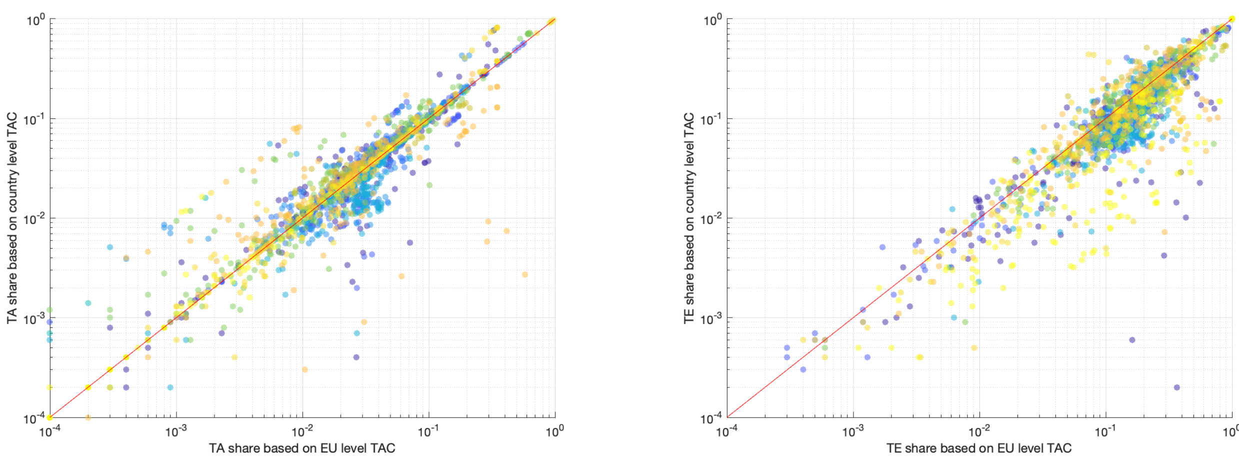

Figure 8: Scatter plot of portfolio TA share (left) and TE share (right) computed using EU-level TAC, TEC (x-axis) and country-level TAC, TEC (y-axis), across combinations of holder sectors,countries and periods.

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