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RESEARCH ARTICLE

A simple indicator for climate-related transition risks of bank lending

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Abstract

We propose a simple indicator for the climate-related transition risks of bank lending based on transaction-level loan data. The underlying idea is that the higher the greenhouse gas intensity of an economic activity, and thus that of the debtor involved, the higher its transition risk. The relationship is mapped through two min-max-normalised functions, each of which represents a scenario for the future characteristics of the green transition. The concept is versatile and applicable to different dimensions at different levels of aggregation (banking system or individual banks, whole economy or specific sectors). As a practical example, we discuss the proposed indicator using Hungarian data for the period 2012–2020.

Keywords: bank lending; climate change; greenhouse gas intensity; risk indicator; transition risk

JEL classification: C43; G21; Q54; Q55; Q56; Q58

1. Introduction

Climate change has moved to the forefront of public discourse as one of the greatest challenges of our time. On a global scale, the process gained momentum with the adoption of the Paris Agreement in 2015 (UNFCCC, 2015). Securing adequate financial resources is a precondition for ambitious transformation, which means that the long-term stability of the financial sector is a key to success.

At the end of the year in which the Paris Agreement was concluded, the Financial Stability Board, an international body that monitors the global financial system, established the Task Force on Climate-related Disclosures (TCFD). The participants in this working group, i.e., financial institutions, investors and climate experts, launched several pilot projects to explore the physical and transition risks of climate change, and over two years they also established practical (now industry-standard) approaches, which included the development of various greenhouse gas (GHG) exposure metrics for financial portfolios (TCFD, 2017*a*, 2017*b*). The financial sector was organised into four groups by activity: banks (lending), insurance companies (underwriting), asset managers (asset management), and asset owners, i.e., public and private pension plans, endowments and foundations (investing). The recommendations on indicators were tailored to the specificities of these sectors. In the headline metric, weighted average carbon intensity (WACI), the values of the investment items relative to the portfolio value are weighted by the related carbon emissions relative to the issuer's revenue (i.e., the result is a tCO2e/euro value; see TCFD, 2017*b*: 43). Prior to this, the financial sector did not have indicators on climate change, i.e., there was no level of transparency upon which stakeholders could base informed decisions. This process paved the way for GHG emissions and GHG intensity to become the main environmental components when talking about the climate-related transition risks of the financial sector.

The Network of Central Banks and Supervisors for Greening the Financial System (NGFS), established at the end of 2017, was an early proponent of transforming TCFD's recommendations into a global standard (NGFS, 2019). A few central banks, e.g., Banque de France (2019) and the Bank of England (2020), embraced the idea early and calculated WACI figures for their own portfolios. They reported the numbers broken down into several elements such as sovereign bonds and equity components within own funds or pension funds. In general, the survey by the NGFS (2020) showed that supervisors had made progress in assessing transition risks based on the portfolios of financial institutions.

In parallel with these international collaborative efforts, the academic scene also developed its solutions. Although this paper focuses on simple concepts, Battiston *et al.*'s (2017) more complex value-at-risk metric of transition risks should also be mentioned for its pioneering nature. Their starting point was the set of high-emitter NACE[1] sections B, C, D, F and H, from which a subsample was extracted and reorganised into 'climate policy-relevant sectors' (fossil fuel, utilities, energy-intensive, housing, transport). Accounting for three asset types (equities, bonds and loans), they showed that portfolios heavily exposed to carbon-intensive sectors could suffer significant losses if the transition to a green economy is disorderly.[2] Note, however, that they applied this metric to euro area banks, and thus they faced the problematics of a data-poor environment, namely the insufficient sectoral granularity of loan aggregates (the European Central Bank (ECB)'s Statistical Data Warehouse is only NACE level 1). When the exposure of the Austrian banks (i.e., only one country's financial system) was examined, Battiston *et al.* (2020) did not face this problem as the dataset was much more detailed (NACE level 4).

Regarding simpler approaches, Monasterolo *et al.* (2017) proposed the combined analysis of two indices: (i) a 'GHG exposure index' that multiplies the relative exposure of the investor's portfolio to different sectors by the relative contribution of those sectors to GHG emissions; and (ii) a 'GHG holding index' that multiplies the sectoral market shares of this portfolio by the relative contribution of those sectors to GHG emissions. With a dataset covering equity holdings and bank loans in the euro area in 2014 (NACE level 1), they concluded that industrial companies and investment funds are the key stakeholders, since they are too big and too exposed (i.e., both indices are high).

The ECB also urged all institutions to develop appropriate quantitative indicators which support the institutions' ability to respond to physical or transition risk events, while they explicitly acknowledged that the definitions of these risk areas are still under

[1] The Nomenclature of Economic Activities (NACE) is the four-level statistical classification system of the economic activities in the European Union. From 2006, its second revision is in force.

[2] Monasterolo *et al.* (2018) showed that (government-backed) development financial institutions are also potentially at risk.

development (ECB, 2020).[3] That is, the floor was essentially open to new ideas, which entailed the necessary evil of losing international comparability. In April 2020, Banca d'Italia published a carbon exposure metric for Italian banks and other financial intermediaries (Faiella and Lavecchia, 2022). They ranked the sectors (NACE level 2) by their share of total emissions and total loans in descending order, took the element-wise average of these two arrays and identified a sector as 'carbon-critical' if it was in the top one-fifth of the resulting array. Note that the two components of this metric are the two factors in Monasterolo *et al.*'s (2017) GHG exposure index if the banking system is taken as a whole and not bank by bank. In March 2021, the Magyar Nemzeti Bank (MNB) presented a risk metric called the Bank Carbon Risk Index, or BCRI (Bokor, 2021; MNB, 2021). The risk of a debtor and thus of its lending bank was provided by mapping the GHG intensity of the debtor to the loan through various functions representing different scenarios. These indicators arrived before the avalanche of new guidelines and proposals from the European Banking Authority, the European Central Bank/European Systemic Risk Board (ECB/ESRB) and the TCFD from mid-2021 (see EBA, 2021; ECB/ESRB, 2021; TCFD, 2021).[4]

It should be stressed that data scarcity (including granularity or sector-classification issues) and reliability were and still are the central factors affecting the applicability of the discussed or related approaches. In 2020, a survey based on 33 central banks and authorities found that data availability and quality were the key concern for 84 per cent of the respondents (OMFIF, 2020). It follows that metrics based on more complete and reliable datasets are definitely preferred.

In this article, we present and discuss the BCRI, including its similarities to and differences from other simple climate-related metrics of bank lending. The central underlying idea of these metrics is that the climate-related transition risks are related to the GHG intensity of an economic activity. The essence, however, is in the details: whether the indicator is just an exposure measure or is something more, i.e., some kind of risk metric; what the characteristics of risk mapping are; how versatile the indicator is in calculating values for subsamples; what the properties (e.g., additivity) of these sub-indicators are, and so forth.

The article is structured as follows. Section 2 presents the methodological background of the BRCI, including the dilemmas and caveats. Using common notations, section 3 compares the BRCI to other similar simple indicators from the literature. Section 4 shows and discusses the results for Hungarian data. Section 5 presents the conclusions.

2. Methodology

One important measure of the environmental burden of an economic activity is its GHG intensity, i.e., the GHG emissions per unit of value added.[5] Given that the global warming potential (GWP) per unit mass of each gas can be several orders of magnitude larger

[3]For an early reflection on transition and physical risks through the lens of a monetary authority, see Batten *et al.* (2016).

[4]Looking at the bigger picture, not just the simple metrics, De Nederlandsche Bank pioneered a series of climate-related stress tests of the financial system (Regelink *et al.*, 2017; Vermeulen *et al.*, 2018, 2019). At the end of 2021, an extensive carbon price stress test of the Polish financial system was also presented (Nehrebecka, 2021).

[5]The denominator can also be output instead of value added, but in our view this approach raises issues when considering risks; we discuss this issue below.

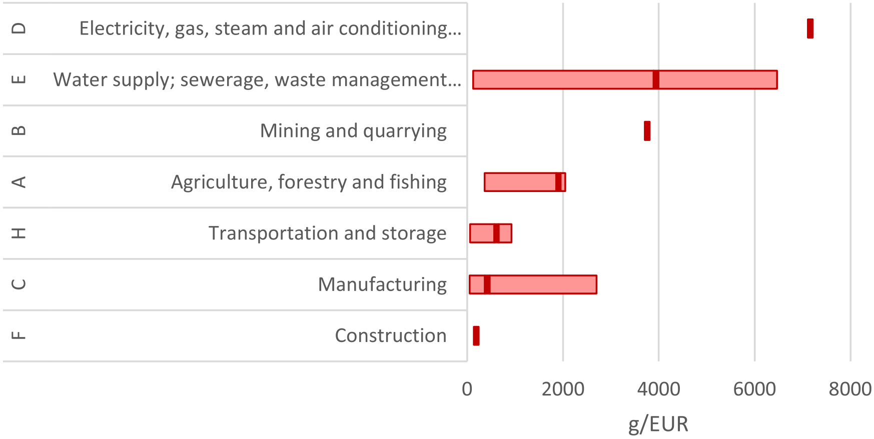

Figure 1. Activities with the highest GHG intensity in Hungary (2017).
Notes: The bars show the dispersion of the sectoral values. There are no divisional GHG statistics for sections B and F. In the NACE classification, section D covers only a single division (D35).
Source: Own figure. Data from Eurostat.

than that of carbon dioxide, the relevant statistics are CO_2-equivalent, i.e., the emitted masses are multiplied by the 100-year global warming potentials (the GWP of CO_2 is 1).[6] Thus, in this article, we use the terms GHG intensity and carbon intensity interchangeably. Annual intensity statistics are provided by Eurostat for each EU country according to NACE classification (with a lag of about two years, once the national GHG inventories are available). The data cover virtually all sections of the economy (level 1: A, B, …, T; except U) and are predominantly, but not always, broken down into individual or grouped divisions (level '2': A01, A02, A03, B, C10–12, …, T).[7] We refer to these elements as 'sectors'. As an example, figure 1 shows the most carbon-intensive activities of Hungary in 2017.

For example, the GHG intensity of mining is orders of magnitude higher than that of construction, but it is only a fraction of the GHG intensity of electricity generation. Differences within individual sections can be similarly large. Within section A, for example, agriculture and fishing represent the two extremes in terms of carbon intensity, providing a good example of the importance of sectoral disaggregation.

2.1 Defining the index

The basic idea is that the rising cost of carbon emissions increases the probability of default of the firms, in particular for intensive emitters. One need but think of a future

[6] The UN Intergovernmental Panel on Climate Change also publishes calculations for 20-year and 500-year time horizons.

[7] In a global context, historical country data are available at the Emissions Database for Global Atmospheric Research (https://edgar.jrc.ec.europa.eu), although only for the main GHG-emitting activities (agriculture, buildings, power industry, transport, waste, other industrial combustion).

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carbon tax[8] or greening consumer preferences, for example. This is in line with the findings of Capasso *et al.* (2020), who showed (based on investment grade fixed-income bonds of 458 companies) that companies with high carbon intensity are perceived by the market as more likely to default. That is, the creditworthiness of brown companies deteriorates, especially following new policy announcements to step up decarbonisation efforts. According to this logic, the transition risks of financial institutions are higher if their lending is directed towards intensive emitters. The question is, however, by *how much*; i.e., what is the relationship between GHG intensity and risk? Note that backward-looking default estimates are not very useful in this regard, since there are many interrelated uncertainties affecting the future. Physical impacts are non-linear and non-normal, policy impacts are uncertain, the transition period spans decades, and the whole issue is burdened by endogeneity (for an overview of the challenges, see Monasterolo (2020)).

We consider two hypothetical scenarios. In the first, we assume that the price of GHG develops sector-neutral, and so the risk is directly proportional to the intensity. In the other, we assume that the anti-carbon measures basically hit the intense polluters, i.e., that the relationship is non-linear. The latter scenario is consistent with the current situation since the EU Emissions Trading System covers only (a subset of) high polluters, which happen to be the intensive polluters as well. For this latter relationship, we assume a Gompertz (sigmoid) curve[9] in a convenient form of $f(GHG) = \alpha e^{\beta \gamma^{\delta \cdot GHG}}$, where *GHG* is the GHG intensity (emission per unit of value added), $\alpha, \beta, \gamma, \delta$ are the shape parameters, and e is the Euler's number. We chose this weight function because of its non-symmetric asymptotes and flexible parametrisation. With the parameters applied, it separates intensive emitters from non-intensive emitters markedly by assigning extreme (i.e., either low or high) risk weights for most of the activities.[10] Figure 2 shows these two exemplary weight functions drawn on the basis of Hungarian data for 2017.

Looking at figures 1 and 2 together, it follows that, for example, mining with linear weighting is only moderately risky, while with Gompertz weighting it bears near-maximum risk, similarly to electricity generation.

The indicator is fed with the end-of-month transaction-level (on-balance and off-balance sheet) outstanding principals of local and foreign currency credits, loans, credit-type agreements and financial leases (hereafter jointly 'loans') provided by other monetary financial institutions to non-financial companies. These principals are multiplied by the risk weights of the debtors' core activity (sector) and the result is divided by

[8] Governments have so far been reluctant to introduce such a tax. Several authors have raised economic, financial or social concerns about this measure (Rausch *et al.*, 2011; Bovari *et al.*, 2018; Mercure *et al.*, 2018; Monasterolo and Raberto, 2018, 2019). The ECB's alternative suggestion, the so-called 'green supporting factor' (i.e., lowering capital requirements for green loans), as well as the complementary approach of a 'brown penalty', also received criticism for potentially endangering the stability of financial system (Campiglio *et al.*, 2018; Thomä and Gibhardt, 2019).

[9] Gompertz was an actuary who, based on his observations, expressed the relationship between death rate and age (Gompertz, 1825).

[10] Were the function $f(GHG) = \begin{cases} 1 & \text{if } GHG > t \\ 0 & \text{if } GHG \leq t \end{cases}$, it would simply be a selector for activities with GHG intensities above threshold *t*. As soon as the governments commit to, e.g., a pre-declared path of carbon tax, such functions can be derived endogenously.

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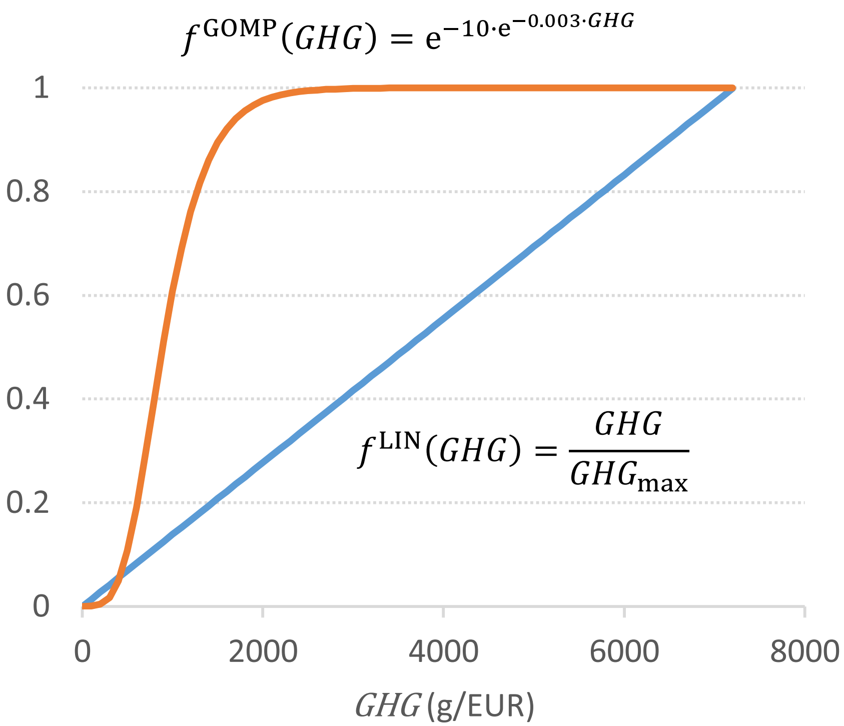

Figure 2. Transition risk weights as a function of GHG intensity.
Note: $GHG_{\max}$ denotes the highest sectoral intensity in the reference year (here: D35 ≈ 7,200 g/EUR; see figure 1).
Source: Own figure.

the total amount of outstanding principals, i.e.,

$$BCRI = \frac{\sum_{i=1}^{I} principal_i \cdot f(GHG_i)}{\sum_{i=1}^{I} principal_i},$$

where i is the index of individual credit transactions, GHG_i is the GHG intensity of the core activity of the debtor of transaction i, and f denotes the abovementioned (0,1]-normalised weight functions.[11] By 'credit transaction' we mean the relationship between a financial institution and a debtor. It implies a more granular approach than a listing by credit agreements since an agreement may cover multiple debtors. In other words, a credit agreement of multiple debtors implies multiple credit transactions here. The advantage of this approach is that the main activity (and thus the riskiness) of debtors may differ, and thus multiple sectors can be linked to a credit agreement. In such cases, in the absence of relevant information, outstanding principal should be divided equally between the debtors.

Note that the underlying variables, i.e., principals, exchange rates, GHG intensities (and also the related parameter I), can change over time. The global picture can therefore

[11] Strictly speaking, the defined sigmoid curve is ∼(0,1)-normalised.

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be calculated by providing the most recent values available for these variables, but partial effects can also be investigated by fixing one or a few variables. If all variables can change, then the frequency of the index calculation is obviously determined by the frequency of the least frequently updated variable (in our case, GHG intensity, which is updated only annually).

Since $0 < f^{\mathrm{LIN}} \leq 1$, it follows that $0 < BCRI \leq 1$ in the linear case. In the sigmoid case, $0 < BCRI < 1$ because of the asymptotic convergence of f^{GOMP}. It implies that if all loans were provided to the most GHG-intensive sector (in the sigmoid case: the group of most GHG-intensive sectors), the value of the indicator would be 1 (in the sigmoid case: very close to 1). If all loans were provided to the least intensive sector, it would be close to 0 (with both functions). Note that the index could be zero only if there was no lending as there is no economic sector with zero GHG intensity, i.e., with zero risk weight.

The indicator can be calculated not only for the whole banking system, but also for sectors or individual banks (banking groups). If it is calculated for sector s, the formula is

$$BCRI_s = \frac{\sum_{j=1}^{J} principal_j \cdot f(GHG_s)}{\sum_{i=1}^{I} principal_i},$$

where j is the index of individual credit transactions of sector s ($J < I$, $s \in \{1, 2, \ldots, S\}$). Note that the denominator embraces the total amount of principals, and consequently $BCRI = \sum_{s=1}^{S} BCRI_s$, i.e., the sub-indices are additive.

When calculating the indicator for a particular bank, both the system-level and bank-level denominator has its rationale. In the first case, the indicator combines the riskiness of a bank with its weight in the banking system. That is, a small bank with a brown portfolio may convey the same risk as a large bank with a green portfolio. In concreto, for bank b, it is

$$BCRI_b = \frac{\sum_{k=1}^{K} principal_k \cdot f(GHG_k)}{\sum_{i=1}^{I} principal_i},$$

where k is the index of individual credit transactions of bank b ($K < I$, $b \in \{1, 2, \ldots, B\}$). Note that additivity also holds here: $BCRI = \sum_{b=1}^{B} BCRI_b$.

In the second case, it shows the individual riskiness of a bank, i.e., a particular bank can be compared to another in terms of 'brownness',

$$BCRI_b^* = \frac{\sum_{k=1}^{K} principal_k \cdot f(GHG_k)}{\sum_{k=1}^{K} principal_k},$$

where obviously $BCRI \neq \sum_{b=1}^{B} BCRI_b^*$.

The index can be rewritten in accordance with the traditional risk concept of PD-EAD-LGD (probability of default, exposure at default, loss given default). To put it simply, our base hypothesis was $PD = g(GHG)$, where function g is unknown except that $g' > 0$ on the whole domain. Since g is bijective, it has an inverse. Let $EAD_i = principal_i$ and $LGD_i = 1$, thus it follows that

$$BCRI = \frac{\sum_{i=1}^{I} EAD_i \cdot f(g^{-1}(PD_i))}{\sum_{i=1}^{I} EAD_i}.$$

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2.2 Controlling for noises

The impact of technological development (change in GHG intensity) or exchange rate movement can be filtered out, depending on the purpose of the analysis. As mentioned above, if the purpose is to obtain an overall picture of the transition, one should load the current values of the variables concerned into the index. On the other hand, if the purpose is to highlight the impact of banking decisions and not a resultant of multiple effects, it should be controlled for these two variables. In this latter case, of course, if the loans are provided and repaid in a way that does not change the sectoral structure of lending, the level of the index remains unchanged. Note also that the consequence of exchange rate fixing is generally much smaller than that of intensity fixing.

Proposition: *The BCRI is not sensitive to the treatment of exchange rates if (i) the riskiness of local and foreign currency denominated loans is similar, or/and (ii) the loans in base currency (in which the calculation is conducted, typically the local currency) dominate the loans in other currencies.*

Proof (i) :

$$\text{Let } x = \sum_{p=1}^{P} principal_p^{\mathrm{LCY}} \cdot f(GHG_p),\ X = \sum_{p=1}^{P} principal_p^{\mathrm{LCY}},$$

$$y = \sum_{q=1}^{Q} principal_q^{\mathrm{FCY}} \cdot f(GHG_q) \cdot FXrate,$$

$$Y = \sum_{q=1}^{Q} principal_q^{\mathrm{FCY}} \cdot FXrate,$$

where, for the sake of perspicuity, we assume that there is only one foreign currency $(P + Q = I)$. The global indicator is then

$$BCRI = \frac{x+y}{X+Y}.$$

A *ceteris paribus* change in the FCYLCY exchange rate with a gross rate of r alters the ratio to

$$BCRI = \frac{x+yr}{X+Yr}.$$

The two ratios are identical if

$$\frac{x+y}{X+Y} = \frac{x+yr}{X+Yr}$$

$$xX + xYr + Xy + yYr = xX + Xyr + xY + yYr$$

$$xYr + Xy = Xyr + xY$$

$$xY(r-1) = Xy(r-1)$$

$$\frac{x}{X} = \frac{y}{Y}. \blacksquare$$

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Proof (ii): Since $\lim_{X\to\infty} x = \infty$ and $\lim_{Y\to 0} y = 0$, it follows that

$$\lim_{\substack{X\to\infty \\ Y\to 0}} \frac{x+yr}{X+Yr} = \lim_{X\to\infty} \frac{x}{X} = BCRI, \ (r \in \mathbb{R} : (0,\infty)). \blacksquare$$

2.3 Dilemmas and caveats

We consider five related issues of the BCRI: (1) the complexity of the index, (2) the risk functions that are applied, (3) data availability, (4) the intensity statistics applied, and (5) the GHG accounting methods.

The index could be made more complex, for example, by incorporating additional weighting in proportion to the duration of loans. Putting more emphasis on long-term loans is consistent with the idea that they are more affected by transition risks, in parallel with intensifying anti-carbon policies. Similarly, it could be amended with a weighting system which considers the concentration of the debtors, as it is not irrelevant whether the exposure to a carbon-intensive company is significant or not compared to the loan portfolio of the provider bank. These are easy to incorporate (even all at once) by using (0,1]-normalised functions for each factor. With such additional elements, the indicator might convey a more sophisticated picture of risks. However, each additional (and simplifying) assumption brings additional arbitrariness into the calculation and, accordingly, the interpretability of the results is questionable. On this basis, even though we have experimented with such calculations, we refrain from discussing these results.

As already pointed out, the assumed functional relationships between GHG intensity and risks are hypothetical at this point. Consequently, for now, changes in the index seem more interesting than the levels of the index. Over time, with a better understanding and by incorporating the ‘true’ relationship(s), levels will also obtain their full meaning.

The general problem of data availability also needs to be emphasised. Currently, risks may be misidentified because of the insufficient granularity of the NACE classification system or Eurostat’s GHG-intensity data. For example, in the case of electricity production (D35), NACE makes no distinction between the sources of the electricity. Consequently, in this model, the GHG intensity and thus the transition risk of coal power plants and solar power plants, for example, are forced to be the same. With historical and contemporary data, it is still not that big of an issue, but it could become one in parallel with significant advances in the green transition. This distortion also holds in the presence of notable nuclear capacities, but due to the lower numbers of such plants, the database would be easier to correct manually. Note that even though the spread of green and nuclear technologies lowers the sectoral (i.e., average) intensity over time, it does not solve the basic problem: the same intensity would be assigned to a more and more dispersed population (until these low GHG-intensity technologies become strongly dominant, of course). Overall, data availability will hopefully catch up with these needs with a future amendment of the NACE classification.

Even if GHG intensities were available in full granularity, central banks might not be able to take full advantage of it. In the Hungarian case, only the core activity of the debtor is recorded in the loan database. Consider a debtor with a very heterogeneous profile. If the loan finances its core activity, the risk weight based on carbon intensity is adequate. However, if this is not the case, for example, if an oil company (section C) builds a solar park (section D) from the loan, it will spoil the interpretation of risks. Additionally, consider a holding company with oil firms as subsidiaries. If the administrative

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holding company is the borrower and it finances its subsidiaries internally, the risks are significantly underestimated since administrative and support activities (section N) feature a modest carbon intensity. These challenges can be handled by flagging green loans in the database. Note, again, that globally we are still at a relatively early stage of the green transition, and so this issue does not necessarily imply a significant bias in the index value at this point.

In this article, we have used GHG emissions statistics related to the unit value added, i.e., the intensity. However, alternatively, the base could have also been the unit output. It is easy to see that the two concepts can lead to very different conclusions. Think of economic activities with huge output, but small value added. These are typically the over-maturing, low profitability companies, of which a growing portion is composed of climate-related stranded assets, such as coal power plants. This was the key aspect in why we preferred the value-added approach.

Finally, national GHG inventories record the emissions by the geographic place of production. This means that a country's footprint is more or less incomplete since the data lack import-related emissions. Consequently, the risks may be underestimated if the imports are significant and stem mainly from carbon-intensive activities. Of course, the inventory would be incomplete with a consumption-based accounting method as well, since in that case, export-related emissions would be missing. These issues, however, go beyond the scope of this article.[12]

3. In-depth comparison with other simple metrics

The concept of utilising GHG emissions as a proxy for climate-related risks is not novel. However, as far as we know, there is no simple indicator which examines the (i) climate-related 'riskiness' of loan portfolios, (ii) with a NACE level-2 GHG-intensity approach, (iii) by incorporating various relationships between GHG intensity and risk.

In WACI, the values of investments relative to the portfolio value are weighted by the related carbon emissions relative to the issuer's revenue. As for resolution, the Scope 1 or 2 GHG protocol was recommended. Scope 1 refers to direct emissions only, while Scope 2 also involves indirect emissions related to the energy consumed (Scope 3 also accounts for the indirect emissions of the whole value chain). Formally, limiting the scope to bank loans and converting to our own notations to highlight the connections and differences, it is

$$WACI = \frac{\sum_{d=1}^{D} loan\ to\ debtor_d \cdot \frac{GHG\ emission\ of\ debtor_d}{revenue\ of\ debtor_d}}{total\ loan} = \frac{\sum_{i=1}^{I} principal_i \cdot GHG_i^{\mathrm{W}}}{\sum_{i=1}^{I} principal_i},$$

where GHG_i^{W} is the revenue-based, Scope 1 or 2 GHG intensity of the debtor of $principal_i$ ($D < I$, as some debtors have multiple loan contracts).

WACI differs from the BCRI in several points. First, it measures a specific carbon emission (in tCO_2e/euro), i.e., it is not a min-max normalised metric, and so its value can be interpreted only in comparison with other values that differ in space, time or asset type. Second, it is based on the emissions of firms/sectors/cities/countries and not only on the emissions of NACE sectors. Moreover, it considers multiple asset types, not just loans. That is, this concept is in some ways more ambitious, and thus its data requirement

[12] Peters (2008) gives an overview of the advantages and disadvantages of the different (pure and hybrid) approaches.

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is much higher. The sample size is very likely to be much smaller than that of an indicator based on Eurostat's national GHG statistics combined with a complete national dataset on bank loans, where under favourable conditions the whole population can be examined, not just a large sample.[13] Third, its carbon intensity factor is based on revenue, which corresponds to output at the sectoral or country levels. As we explained above, we have fundamental concerns with the output approach, and we argue for using carbon intensities based on gross value added. Nevertheless, in any case, consistency should be maintained, and so we disagree with the common practice of mixing the concepts, i.e., the use of revenues by firms (which is an output concept) and GDP by countries (which is a value-added concept). Fourth, it is more of an 'exposure' metric rather than a 'risk' metric, since it does not account for various relationships between carbon intensity and risk, which the BCRI does, undoubtedly in a very simplistic way (for now). Fifth, it is probably more exposed to greenwashing and brownwashing. Companies have incentives to overstate and understate their environmental efforts (see Kim and Lyon, 2014), while the non-profit agents that estimate and validate the national GHG inventories from multiple sources might be less exposed to such incentives.

In the two-dimensional approach of Monasterolo *et al.* (2017), the two indices for bank b are (with our own notations and narrative)

$$\begin{aligned} \textit{GHG exposure index}_b &= \sum_{s=1}^{S} \left(\frac{\textit{loan to sector}_s \textit{ by bank}_b}{\textit{loan to all sectors by bank}_b} \right. \\ &\qquad \left. \cdot \frac{\textit{GHG emission of sector}_s}{\textit{GHG emission of all sectors}} \right) \\ \textit{GHG holding index}_b &= \sum_{s=1}^{S} \left(\frac{\textit{loan to sector}_s \textit{ by bank}_b}{\textit{loan to sector}_s \textit{ by all banks}} \right. \\ &\qquad \left. \cdot \frac{\textit{GHG emission of sector}_s}{\textit{GHG emission of all sectors}} \right). \end{aligned}$$

Although the factors in the sums are theoretically between 0 and 1, and thus the range of both indices is between 0 and 1, the concept is very different from that of the BCRI. The two indices above together form a market-relevancy-augmented exposure metric, which does not say anything about the relationship between exposure and policy/market risks (which the BCRI attempts to do with the functions discussed). This description also applies to the metric of Faiella and Lavecchia (2022), where the score for sector $\hat{s}$ is the average of the related elements of two linearly ordered sets (with our own notations),

$$\frac{\begin{array}{l}\left(\mathrm{rank}^{(\hat{s})}\left(\left\{ \frac{\textit{loan to sector}_s}{\textit{loan to all sectors}} \,\middle|\, s = 1, 2, \ldots, S \right\}, \geq \right)\right. \\ \qquad \left. + \,\mathrm{rank}^{(\hat{s})}\left(\left\{ \frac{\textit{GHG emission of sector}_s}{\textit{GHG emission of all sectors}} \,\middle|\, s = 1, 2, \ldots, S \right\}, \geq \right)\right)\end{array}}{2},$$

where operator $\mathrm{rank}^{(\hat{s})}$ gives the position of sector $\hat{s}$ within the ordered set of S elements.

[13]See, for example, the strongly selective sectoral coverage of GHG Protocol calculators available at https://ghgprotocol.org/calculation-tools#sector_specific_tools_id.

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4. Results for Hungarian data

In many countries, GHG intensities have declined markedly in recent years. In Hungary, GHG intensity fell by 30 per cent from 2007 to 2017 considering the whole economy. Naturally, the rates of change in different sectors are significantly dispersed, and moreover, there are sectors with increasing values. These increases are mostly due to the base effect, but there are some remarkable exceptions such as manufacturing of coke and refined petroleum products (C19), paper products (C17) or printed media (C18), with 70 to 100(!) per cent increase rates.

Recall that if the indicator is calculated with unfixed variables, it is basically driven by two effects: the change in the sectoral composition of the loan portfolio and the change in the GHG intensity of sectors. As the intensity values show a predominantly downward megatrend, it seems of little interest to present the evolution of the values of the unconstrained indicator, as it is dominated by these megatrends. Instead, we focus on examining the structural transformation of the loan portfolios by fixing the risk weights based on the most recent intensity values available (at the time of the study). That is, all of the presented figures reflect the dynamically changing monthly loan portfolios with fixed GHG intensities (2017) and fixed exchange rates (31 December 2019) used to convert foreign currency-denominated loans into Hungarian forints. Note that the differences between results with spot and fixed exchange rates are tiny.

The source of Hungarian loan data is the Central Credit Information System (Központi Hitelinformációs Rendszer, KHR). The debtors' sectoral classification is not available for foreign companies that do not have a Hungarian tax number, and thus they are excluded from our calculations. The sectoral classification of sole traders and proprietorships are intermittently incomplete, so we also ignored these entities. In the examined time period, on average, all these excluded entities account for only one-fifth of the total amount of the outstanding principals.

Figure 3 shows the evolution of the BCRI for the whole banking system under the two hypothesised risk weights.

It can be seen that there was a significant drop in the risks after the middle of the last decade. This is similar to the findings of ECB/ESRB (2020) that most banks in a sample of the 90 largest euro area banks decarbonised their portfolios between 2014 and 2017. However, after a sideways movement in 2018, BCRI skyrocketed again in 2019, leading to a long-unseen increase in the annual moving average. This reversal was basically due to loans provided to a few carbon-intensive companies, of which some belonged to the same corporate group. This can be clearly seen in figure 4, which shows the evolution of the indices of the most risky activities.

It can be seen from the figures that the decline in the global index after the middle of the decade was primarily due to a reduction in agricultural exposures. In the final years, risks rose sharply, mainly driven by loans financing electricity production and chemical activities, just like the case with the chemical industry in 2014, or with the electric power industry at the middle of the decade. Nevertheless, upward pressure is also perceivable in other sectors. All of these perfectly exemplify that the carbon risk of the Hungarian banking system is fundamentally influenced by a handful of large, carbon-intensive corporations. Of course, this relationship holds for all small countries where the credit market is relatively small compared to the credit needs of large transnational corporations.

Looking under the bonnet, figure 4 reveals the sectoral distribution of the loans as it covers all sectors of the economy. For example, as the risk weight of D35 is 1 in the linear

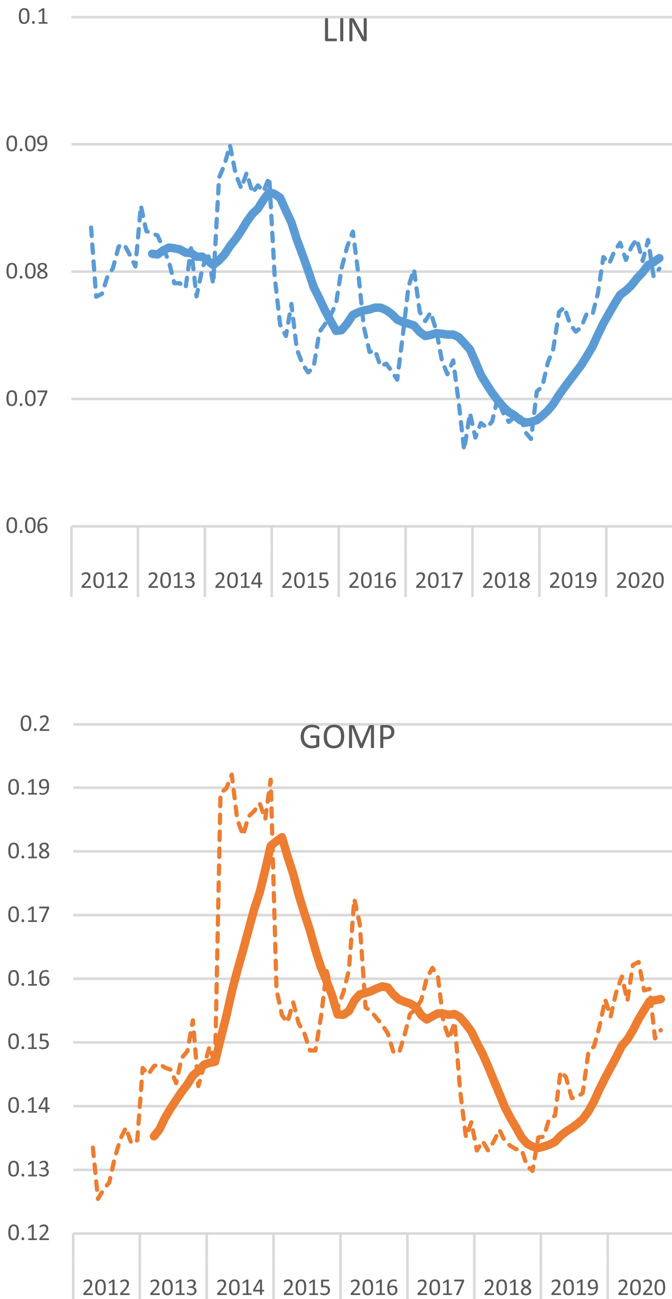

Figure 3. Monthly values of the banking system BCRI with 12-month backward-looking moving average (GHG intensities: 2017; exchange rates: 31 December 2019).
Note: Transaction-level outstanding principal data are available from April 2012.
Source: Own figure. Data from MNB/KHR (loan data), MNB (exchange rates) and Eurostat (GHG intensities).

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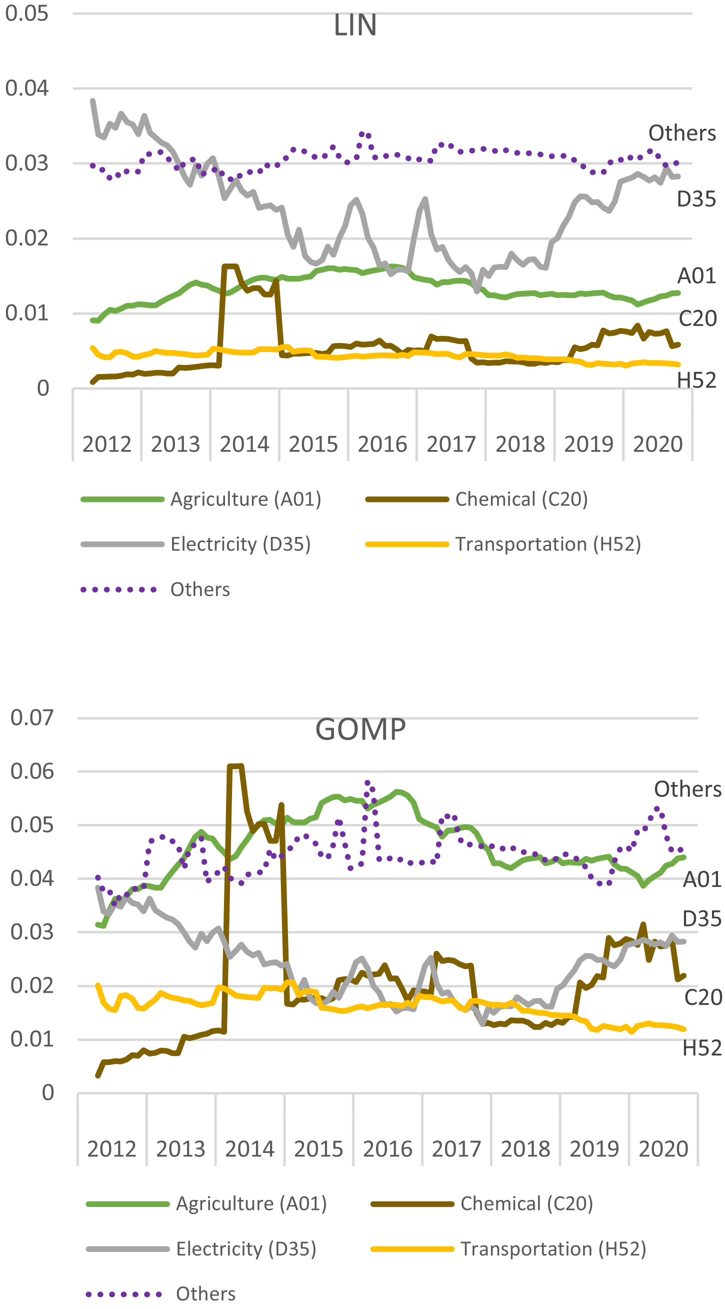

Figure 4. Monthly values of the sectoral BCRI (GHG intensities: 2017; exchange rates: 31 December 2019).
Note: Recall that the denominator covers the entire banking system, and so the sectoral indices are additive (see $BCRI_S$).
Source: Own figure. Data from MNB/KHR (credit data), MNB (exchange rates) and Eurostat (GHG intensities)

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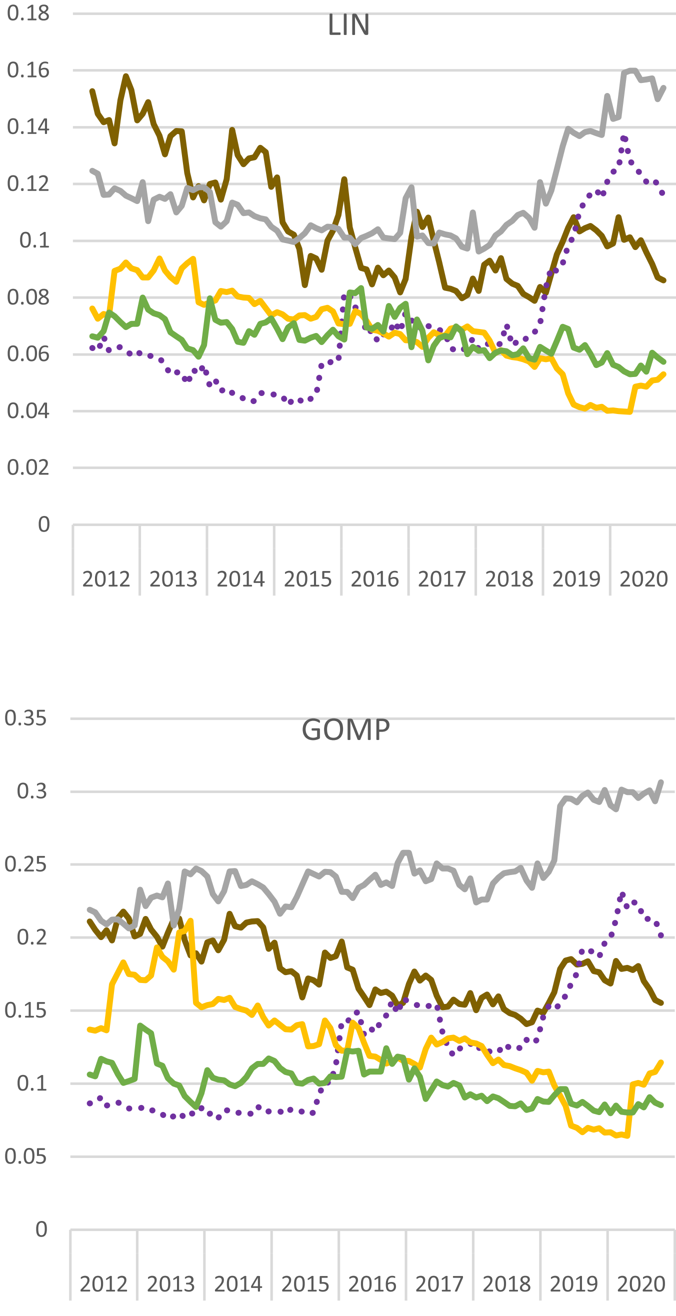

Figure 5. Brownness of five anonymised banks (monthly values of the bank-level BCRI) (GHG intensities: 2017; exchange rates: 31 December 2019).
Note: The denominators here are the loan portfolio of the bank in question (see BCRI_b^*).
Source: Own figure. Data from MNB/KHR (credit data), MNB (exchange rates) and Eurostat (GHG intensities).

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case, it follows that the share of loans provided to such companies varied between 1.5 and 4 per cent during the examined period. Additionally, the category 'Others' that involves all but the four sectors displayed is only as risky as a single, but influential sector, namely D35 in the linear case and A01 in the Gompertz case. Moreover, in the Gompertz case, as the risk weights of these two sectors are close to 1, and the BCRI value of A01 is roughly one and a half times that of D35 at the end of 2020, it implies that the former had roughly one and a half times as much in loans as the latter at that time.

As far the brownness of the portfolios of individual banks, the picture is very diverse (figure 5).

Looking at the depicted banks, we can draw interesting conclusions. First, some banks consistently provide more loans for browner activities, while others do so for greener activities. Second, some institutions are gradually shifting towards greener sectors, while others are drastically increasing their involvement in browner sectors. Third, a bank's portfolio can change significantly in just a few years.

5. Conclusions

Climate change creates the need for new tools and frameworks that can shed light on the threats to the financial system. Pioneering stress tests of climate-related physical and transition risks over a 30-year window became the flagship of this new line of thinking. However, because of the paradigmatical novelty of these experiments and the long time frame itself, such exercises require huge human and data resources, while inevitably involving unpleasantly large uncertainties. Under such circumstances, simple complementary devices come in handy.

We have provided an indicator for the climate-related transition risks of bank lending based on the assumption that the higher GHG intensity of an economic activity results in more climate-related transition risk because of the increasing future carbon price, greening consumer preferences, etc. We argue that the incorporation of various risk functions, the high-detail linking of loans (loan parts) to riskiness, the min-max-normalisation, and the versatility of bank and sectoral sub-indices provide novel perspectives. Nevertheless, we believe that the indicator presented in this article complements rather than replaces any other simple tool, as it also simplifies reality and consequently also has its issues.

The methodology presented can be easily applied to any country which has a credit register with comprehensive transaction-level outstanding principal data and sectoral classification records. Consequently, the potential users could be primarily the central banks. We showed the development of the BCRI for the Hungarian banking sector from 2012 to 2020 in different dimensions and aggregation levels.

Even if the indicator warns of deteriorating prospects, this does not necessarily imply that lending should not be provided to sectors exposed to excess risks. It indicates that banks and regulators should be aware of the magnitude and evolution of these risks. The Paris Agreement gave momentum to the restructuring of economies towards green solutions. However, the reactions so far have been asymmetric: green returns and thus the capital inflows into these activities were rising, while brown investments were not, or only slightly, penalised (see e.g., Delis *et al.*, 2019; Kruse *et al.*, 2020; Monasterolo and De Angelis, 2020). In other words, the opportunities are immediately utilised, while the risks are hardly acknowledged. Under such circumstances, any metric that promotes the integration of climate awareness into stakeholders' long-term risk management is useful. Especially if enough information is gathered in the future to endogenously derive a function that reasonably represents the transmission between GHG intensity and risk.

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