An initial analysis of energy transition risks using the Banco de España's FLESB stress-testing framework

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Abstract

This article contains the Banco de España's initial analysis of the energy transition risks' impact on the banking sector, using its Forward Looking Exercise on Spanish Banks (FLESB) in-house stress-testing framework. Different macroeconomic scenarios, linked to higher prices and the extended coverage of the emissions trading system, with a three-year time horizon are considered. In this exercise, the probability of default of the business lending portfolios was modelled with a high level of granularity, by enterprise size and by sector, to capture these transition risks' uneven impact on them. The other risk factors and balance sheet and income statement items are also projected consistently with the macroeconomic scenarios in order to obtain estimates for the institutions' profitability and solvency. Overall, the scenarios have a moderate impact on the credit quality of business lending; however, those sectors with greater greenhouse gas emissions are significantly more affected. Nonetheless, the exposures to these more affected sectors account for a relatively limited percentage of the Spanish banking sector's total lending. As a result, the ultimate impact on profitability is also muted. While the analysis conducted is an initial and partial approach to measuring transition risk, by focusing on the short term, it helps reduce uncertainty over the costs of the energy transition process.

Keywords: climate-related risk, transition risk, stress tests, probability of default, profitability, solvency.

1 Introduction

The physical risks stemming from climate change, associated with environmental degradation and a higher frequency of extreme events (e.g. prolonged droughts, fires and flooding), are a new source of risk to the financial sector. In light of these risks, fiscal and environmental policies play a key role in reducing carbon dioxide emissions and driving the transition to a more sustainable economic model in which the physical risks of climate change are held down at low levels. However, these economic transition policies entail a series of costs for certain sectors, which could stifle economic activity in the near future and also pose risks to the financial sector. Both types of risk can materialise in tandem as the measures to mitigate them may be applied late or inadequately, when climate change has already at least partially occurred.

In this setting, regulatory and supervisory authorities have started to develop analyses and tools to model and assess the impacts of climate change on financial stability. Sensitivity analyses and stress tests provide a sound methodological basis for a forward-looking analysis of climate-related risks, given these risks' uncertain nature. This is prompting the development and adaptation of these forward-looking methodologies to the specific characteristics of these risks.

The most significant climate-related risks to the financial sector are generally related to the credit exposures and market exposures to other sectors, including those which are exposed to extreme weather events or to the costs of transitioning to a more sustainable economy. It is therefore necessary to construct macro-financial stress scenarios that capture the heterogeneity of the physical and transition risks specific to each sector. It is also necessary to adapt the stress tests to analyse in more granular detail the sectoral exposures and their associated risks on the basis of these scenarios with uneven impacts across sectors.

In this regard, the Banco de España's first step has been to develop a framework for analysing the impact on the banking sector of risk scenarios associated with the initial phases of the implementation of transition policies in Spain. Specifically, the pre-existing top-down Forward Looking Exercise on Spanish Banks (FLESB)[1] framework has been adapted for this purpose.

The macro-financial scenarios used for this exercise were designed in-house by the Banco de España and are based on the higher price of emission allowances and on different extensions of the coverage of the Emissions Trading System (ETS) for an extensive breakdown of over 50 sectors. These changes to environmental legislation are reflected in different shocks over a three-year analysis horizon to the real gross value added (GVA) growth paths for that sectoral breakdown.

The Banco de España's Central Credit Register (CCR) was used to model different risk parameters relevant to the exercise. Very granular data are thus obtained on the credit exposures to non-financial corporations and sole proprietors, including information on their repayment situation and the debtor's sector of economic activity, among other characteristics. An additional advantage of this database is its long-running time series. It has been used in this application to form datasets since 2000.

The probability of default[2] (PD) of banks' business lending exposures is estimated using the CCR database separately for each sector and enterprise size (large firms, SMEs[3] and sole proprietors). These PDs are stressed by taking into account the sectoral shocks to the transition scenarios' GVA growth, in addition to the attendant

1 The results of the FLESB are published regularly in the Banco de España's *Financial Stability Report*.

2 In this article PD means the probability a performing loan will be classified as non-performing within 12 months, i.e. the probability of it being migrated from Stage 1 to Stage 3 over that time frame.

3 The distinction between large firms and SMEs is consistent with the European Commission Recommendation concerning the definition of micro, small and medium-sized enterprises (see European Commission (2003)). Therefore, large firms are those with 250 or more employees and an annual turnover of over €50 million or whose balance sheet total exceeds €43 million.

deterioration of the financial position (profitability, leverage, etc.) of each sector of activity. The other parameters and sources of income and loss for the banks are also stressed using the FLESB framework on the basis of the impact of the transition scenarios on the aggregate macroeconomic forecast for the overall economy.

The results obtained point to a moderate deterioration in credit quality in PD terms that is, however, markedly uneven across economic sectors. Thus, under the most severe scenario, over a three-year horizon and in the face of the implementation of environmental policies combating emissions, the average PD in that period could increase by up to 0.8 percentage points (pp) compared with the baseline scenario in the most affected sector (manufacture of coke and refined petroleum products). The impact on profitability is also moderate and varies based on the relative share of operations in Spain (the jurisdiction where the introduction of the environmental policy is being studied) and its sectoral composition. Cumulative profitability as a percentage of risk-weighted assets (RWAs) could fall by between 0.19 pp and 0.41 pp over the horizon analysed. The results therefore suggest that the banking sector would be capable of absorbing the costs stemming from the commencement of climate transition policies; however, some banks' profitability would be hit harder. The banking sector's solvency would not be materially impaired as a result of the introduction of the environmental policy considered.

The rest of this article is structured as follows: Section 2 examines the goals and context of the exercise; Section 3 presents the short-term sectoral transition scenarios used; Section 4 details the methodological approach developed to adapt the PD to a climate-related risk exercise; Section 5 sets out the results obtained in terms of PD and profitability; and Section 6 summarises the main conclusions. The article includes an annex containing complementary methodological information.

2 Goals and context of the exercise

This article analyses the materialisation of risks stemming from the transition to a more sustainable economy over a three-year horizon, without examining the possible materialisation of physical risks or longer time frames. Measuring the macroeconomic impact of the physical risks is particularly complex since it requires the explicit modelling of the relationship between economic and environmental conditions,[4] and since such impact materialises over long time horizons. The Banco de España's future research will develop the data sources and macroeconomic models necessary for examining this type of scenario. However, this initial examination of the transition costs, which is more feasible using the available techniques, currently enables the measurement and assessment of the costs of these early policies to fight climate

4 See Box 3.2 of the Banco de España's Autumn 2021 *Financial Stability Report* for an analysis of the quantification of the effect of environmental disasters on real estate wealth at regional level.

change. If these costs are moderate, the transition policies are easier to implement, despite uncertainties enduring long term.

Other initiatives to quantify climate-related risk using forward-looking methodologies include those by the Network of Central Banks and Supervisors for Greening the Financial System (NGFS), such as the *Guide for Supervisors,*[5] the *Guide to climate scenario analysis for central banks and supervisors,*[6] the NGFS' risk scenarios and other supporting documentation[7] published between May 2020 and July 2021. At European level, different working groups have addressed the methodological progress and specific features of these models, which have been reflected in the documents *Climate-related Risk and Financial Stability*[8] and *Positively Green. Climate Change Risks and Financial Stability.*[9]

With regard to the first practical applications of forward-looking methodologies by national supervisors and regulators, of note is the work to quantify the impact of climate change on financial stability in France[10] and the Netherlands.[11] These latest exercises also include the estimated impact for insurance companies and pension schemes. The Bank of England has disseminated the basis for its climate-risk exercise,[12] the results of which will be published in 2022. Baudino and Svoronos (2021) compare the methodologies used, the objectives covered and the results currently available. Many other national authorities are conducting climate stress tests on their banks or on the financial system as a whole (see European Central Bank and European Systemic Risk Board (2021)). The ECB has also developed its own top-down analysis framework (ECB economy-wide climate stress test)[13] with a view to assessing the exposure of euro area banks to climate-related risks.

The ECB's exercise is different from the one presented in this article in terms of the sample of institutions, methodology, type of climate-related risks considered and time horizon. The ECB's work stands out due to the breadth of its cross-section at European level, as it covers approximately 4 million firms and 2,000 banks, and extends the analysis of the transition risks to also include the impact of physical risks over a 30-year period. The results of the ECB's work show that, if no measures are applied, the costs stemming from extreme weather events rise substantially, thereby increasing the firms' PD. However, the long-term benefits of implementing prompt measures that drive the transition to a green economy would offset those firms'

5 See Network for Greening the Financial System (2020a).
6 See Network for Greening the Financial System (2020b).
7 See Network for Greening the Financial System (2021 and 2020c).
8 See European Central Bank and European Systemic Risk Board (2021).
9 See European Systemic Risk Board (2020).
10 See Allen et al. (2020) and Autorité de Contrôle Prudentiel et de Résolution (2021).
11 See Vermeulen et al. (2018 and 2019).
12 See Bank of England (2021).
13 See European Central Bank (2020) and Alogoskoufis et al. (2021).

short-term costs. The preliminary analysis of the impact of physical risks on credit quality in Spain also points in the same direction.[14]

The methodological basis for quantifying climate-related risk and the first exercises conducted by the authorities are a benchmark for banks. In this regard, supervisors and authorities have also published guides and action plans encouraging banks to be proactive and to factor climate-related risks into their business strategies and risk-management processes.[15]

3 Scenarios

This exercise's scenarios were prepared in-house by the Banco de España using the *Sectoral Carbon Tax* (referred to as CATS) model, in accordance with the methodology published by Aguilar, González and Hurtado (2021). The model has a highly detailed sectoral structure and is designed to capture the impact of transition risks over time horizons of two to five years. It is a general equilibrium model that enables the simulation of the impact of shocks on the Spanish economy. Particular importance is attached to the sectoral asymmetries based on how intensively they use different types of energy. The model takes into account the interconnectedness summarised by the input-output table data for the Spanish economy and replicates its main characteristics in terms of productive system, energy intensity, emissions by type of technology, etc.[16] The application of the model enables the projection of different GVA growth paths for 51 non-energy sectors and for two energy production sectors ("fuel" and "electricity"),[17] based on their specific transition risks and other macroeconomic variables of interest for the stress-test exercise.

14 See Box 3.1 of the Banco de España's Autumn 2021 *Financial Stability Report* for a simplified analysis of the long-term impact of physical risks on PD.

15 In December 2019 the European Banking Authority published its action plan on sustainable finance (see European Banking Authority (2019)). In November 2020 the ECB published its guide on climate-related and environmental risks for banks (see European Central Bank (2020)). In the same vein, in October 2020 the Banco de España published the supervisory expectations document on risks posed by climate change and environmental degradation (see Banco de España (2020)). Like in the ECB's guide, climate-related and environmental risks are recognised as sources of financial risk and guidelines are provided for less significant institutions regarding how they should incorporate and address climate-related and environmental risks, including the preparation of stress tests.

16 To obtain the elasticities of substitution between the different types of goods, a mixed calibration was used in which the elasticity of substitution between non-energy goods was set at 0.9 in accordance with the literature and the model in Devulder and Lisack (2020), and only the value of the elasticities of substitution between energy and non-energy goods, or between different energy goods, is calibrated.

17 The two energy sectors differ as regards the amount of emission allowances associated with each, and also in the way in which the simplified specifications of the model relate to the more complex real world structures. In the case of fuels, their production does not generate a large amount of emissions, but their use does; the agents who use the fuels have to acquire the associated emission allowances, while the fuel producer receives a price that does not include the amount corresponding to such rights. Electricity, in contrast, generates emissions when it is produced, but not necessarily when it is used. Thus, electricity users do not need to acquire emission allowances, but simply pay a price to electricity producers, who are responsible for obtaining the necessary emission allowances to be able to produce that electricity.

The starting point for the design of the scenarios for this exercise is a baseline scenario, which assumes growth close to the Spanish economy's structural growth, more akin to pre-COVID-19 growth, considering that these measures will be implemented in a normal economic environment. Taking this baseline scenario, the effects of different shocks are estimated on the basis of the implementation of measures aimed at transitioning to a low-carbon economy, resulting in the following scenarios:

i) Higher emission price scenario: this scenario entails increasing the price of a tonne of CO_2 equivalent from €25 (2020 average) to €100 (the current regulatory limit, given that it is the amount to be paid in the event of insufficient emission allowances). This increase is comparable in relative terms to previous increases (the annual average rose from €6 to €25 per tonne between 2017 and 2019 and, after holding at €25 on average in 2020, has already risen in recent months to above €50). In three years this shock would prompt a total reduction in emissions similar to that of the orderly transition scenario prepared by the NGFS, which for the Spanish economy would be close to 10% over this time horizon.

ii) Extension of ETS coverage to all business sectors scenario: this scenario entails all emissions becoming levied, irrespective of the sector producing them. It prompts a smaller reduction in emissions but a very different sectoral impact; the high-emissions sectors that are currently exempt from the emission allowances system would be harder hit.

iii) Combined shock scenario: this scenario causes a far greater stress scenario, given that it is equivalent to first raising the price of emissions and then extending the coverage to all sectors, rather than just the sum of the two preceding scenarios. Moreover, this second step is performed at the new €100 per tonne price, rather than the original €25 per tonne price. Over the three-year time horizon, this scenario prompts a somewhat larger reduction in emissions than that under the Net Zero 2050 scenario of the NGFS.

iv) Combined shock scenario, also envisaging the extension of ETS coverage to households: this is a combination of scenario iii) and the application of the ETS to households for their direct fuel consumption. It prompts a somewhat greater reduction in emissions than in scenario iii) (under which households were not levied) and above all a greater cost in terms of GDP, given that the shock triggers a greater income effect.

Other technical characteristics that were considered in the CATS model to design these scenarios will be detailed in a forthcoming occasional paper. These include the assumption that higher tax revenues resulting from any of the above-mentioned shocks are channelled back to households (which in the model are business owners)

Table 1
IMPACT OF THE SIMULATED SHOCKS ON ECONOMIC ACTIVITY

Differences in the cumulative rates of change (t+1, t+2, t+3) compared with the baseline scenario.

		Range of impact on non-energy sectoral GVA (a)	
	GDP	Lower bound	Upper bound
Higher emission prices	-0.6	-5.3	0.1
Extension of ETS coverage	-0.3	-2.1	0.1
Combination	-1.3	-8.4	0.3
Combination, including extension to households	-1.9	-9.1	0.3

SOURCE: Banco de España.

a The lower bound of the range of impact on the sectoral GVA in each scenario is the most negative difference between the cumulative rates of change in the three years of the exercise and the corresponding measures under the baseline scenario. The upper bound is the analogous most positive difference. The scenarios 1) higher emission allowances prices; 2) extended ETS coverage; 3) combination (of the two shocks); and 4) combination, including extension to households, match those in the text with the same numbering.

via lump-sum transfers.[18] It is also necessary to examine with caution the scope of the transition scenarios considered, which do not cover all their possible types.[19] This is because part of the adjustment and resource-reallocation costs are not included – specifically, capital, the treatment of households as homogeneous agents and the exclusion of the effects via global trade – with the focus being placed on the effects of domestic demand. Also, it is assumed that the rise in energy prices in the scenarios is insufficient to cause permanent increases in inflation that feed through to interest rates or translate into sharp financial market corrections or significant shocks to house prices. Therefore, the effects of the shocks reflected in the scenarios could be considered a lower bound.

Table 1 shows that the most severe shock, captured by the scenario combining the higher emission allowances prices and the extension of the ETS to firms and households, would result in a 1.9 pp smaller cumulative change in GDP over three years than under the baseline scenario. The other scenarios would result in differences in cumulative GDP of between -1.3 pp and -0.3 pp compared with the baseline scenario.

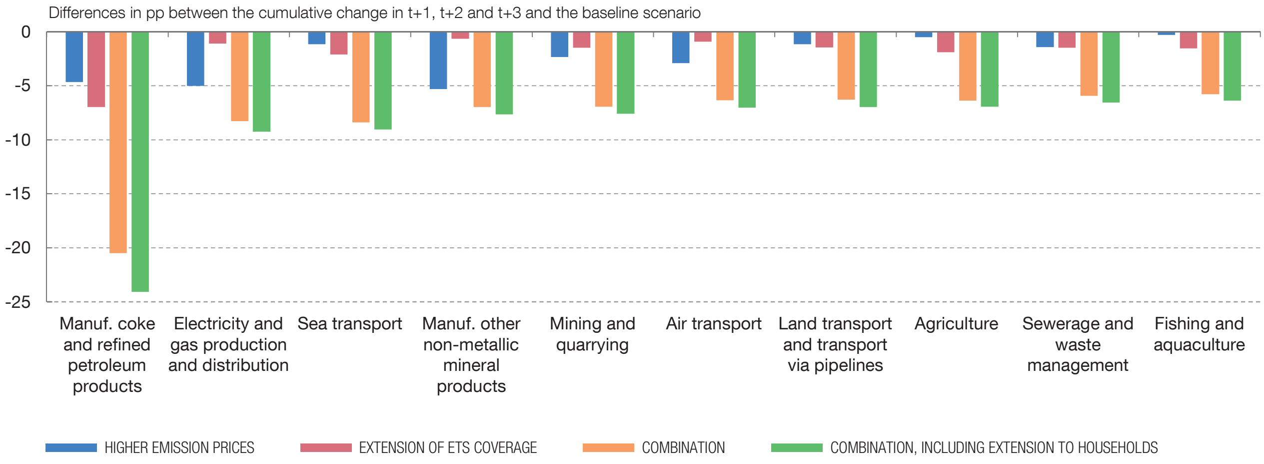
Further, the sectoral impact differs widely under all the scenarios, as demonstrated by the lower and upper bounds. Indeed, the GVA of some of the sectors considered by the model is stressed far more than aggregate GDP, especially under the scenarios with bigger shocks, as Chart 1 shows in greater detail.

18 If the higher tax revenues were channelled back via lower taxation on employment, the simulation would include an expansionary supply shock, which, as is quite common in the literature, can exceed the adverse effect of the tax on emissions. Given that the aim is to generate stress scenarios, the use of lump-sum transfers seems more appropriate.

19 See Box 3.1 of the Banco de España's Autumn 2021 *Financial Stability Report*, which also expresses caveats as regards the scope of the transition scenarios considered.

Chart 1

CUMULATIVE DROPS IN GVA COMPARED WITH THE BASELINE SCENARIO (a)



SOURCE: Banco de España.

a From left to right the chart depicts the ten most affected sectors, ordered by the impact of the scenario combining higher emission allowances prices and the extension of the ETS to firms and households (most severe scenario).

4 Modelling of the probabilities of default by economic sector

4.1 General framework

The proposed framework models the PD of the exposures to businesses and considers a granular breakdown by bank, economic sector and business size. Business size is broken down into three categories: sole proprietors, SMEs and large firms.[20] In addition to the most aggregated macro variables (interest rate level, unemployment, growth of house prices, etc.), GVA growth disaggregated by sector and financial ratios obtained for groups of businesses by sector and by size were also considered.

It should be borne in mind that the other factors of bank risk and balance sheet and income statement items that are projected in the exercise, such as the value of the collateral provided, net interest income and RWAs, are also consistent with the proposed climate scenarios; however, PD is the channel through which the sectoral heterogeneity reflected therein is introduced. These other factors are projected on the basis of the aggregate macroeconomic variables consistent with the sectoral scenarios.

20 We examined the possibility of a more granular business-size breakdown; specifically, by distinguishing, within the SME group, between microenterprises (fewer than 10 employees), small enterprises (10-49 employees) and medium-sized enterprises (50-249 employees). This breakdown would be interesting, as the three groups have different characteristics, notably the quantitative importance of the microenterprise group and its specific limitations in access to credit, typically reflected by the use of mortgage guarantees. However, under the models used, obtaining, for the estimation, a sufficiently representative number of businesses with the additional breakdown by size would be impracticable in many sectors. Future research will consider how to expand the analysis of the corporate sector.

4.2 Specification

The PD is calculated at bank level for different economic sector and business size groups.[21] Thus, pd_t^{bsg} denotes the PD in the period $t = 1,\ldots,T$ of the businesses linked to the bank $b = 1,\ldots,B$, in economic sector $s = 1,\ldots,S$ and of size $g = 1,\ldots,G$.

For the sectoral dimension, some additional aggregates are considered. These will be necessary if there is an insufficient number of observations to perform the estimation in certain sectors. It is assumed that each economic sector s belongs to one (and only one) group of similar sectors or "industry" $r = 1,\ldots,R$, with $R < S$. pd_t^{brg} denotes the PD of that industry. Similarly, a is the aggregate of all the sectors, with the related PD equal to pd_t^{bag}.

The PD pd_t^{brg} is consistent with the average (weighted by number of debtors) of the PDs of the comprising sectors (for a given year, bank and size). Similarly, pd_t^{bag} is the weighted average of all the sectors and, in turn, of all the industries. To simplify the notation, the index i runs through all the sectoral components: the S sectors, the R industries and the total aggregate, such that $i = 1,\ldots,I$, where $I = S + R + 1$. These elements are called "units".

A logit link function is used in the PD modelling. Thus, pd^* is defined as:

$$pd^* = \ln(pd) - \ln(1 - pd) \quad [1]$$

With its inverse:

$$pd = \exp(pd^*) / (1 + \exp(pd^*)) \quad [2]$$

Three types of explanatory variables are considered:

- GVA growth in the period t, for the sector, industry or total aggregate, and for its first lag: $rvag_t^i$ and $rvag_{t-1}^i$. This variable is the same for all banks and business sizes.

- A vector of other M macro variables: $m_t = (m_t^1,\ldots,m_t^M)$. This vector is the same for all banks, units and sizes. No lags are considered for this vector.

- A vector of J aggregate financial ratios by unit and size: $f_t^{ig} = (f_t^{1ig},\ldots,f_t^{Jig})$. This vector is the same for all banks and no vector lags are considered.

21 It is useful to highlight that, throughout this article, PD always refers to the aggregate PD of a certain group of exposures of businesses determined by the economic sector to which they belong, their size or the bank to which the exposure relates. Similarly, the financial ratios are always aggregate values of groups of businesses determined by their sector or size (in this case, not by the bank to which the exposure relates).

With these components, for the transformed PD the framework proposes a different panel model of B banks for each unit and size:

$$pd_t^{*big} = \alpha^{ig} + \rho^{ig} pd_{t-1}^{*big} + \beta^{0ig} rvag_t^i + \beta^{1ig} rvag_{t-1}^i + \theta^{ig} m_t + \delta^{ig} f_t^{ig} + e_t^{big} \quad [3]$$

Where α^{ig}, ρ^{ig}, β^{0ig} and β^{1ig} are scalars, while θ^{ig} and δ^{ig} are vectors. The variable e_t^{big} is an error component.[22]

Paths of the explanatory variables in expression [3] are required to project pd_t^{*big} for periods longer than T. The paths for GVA growth and for the vector of the macro variables are part of the scenarios. However, the financial ratios are generated internally within the framework.

Accordingly, we opted for a panel model of the S sectors for each financial ratio $j = 1,\ldots,J$, in each size $g = 1,\ldots,G$, on the basis of the specification:

$$f_t^{jsg} = c^{jsg} + \varphi^{jg} f_{t-1}^{sg} + \gamma^{jg} rvag_t^s + \vartheta^{jg} m_t + u_t^{jsg} \quad [4]$$

where c^{jsg} are sectoral fixed effects for each financial ratio and size, γ^{jg} is a scalar and φ^{jg} and ϑ^{jg} are vectors. u_t^{jsg} is an error component. These financial ratio dynamics, summarised in the parameters of the model in [4], are applied for simplicity to all levels of sectoral aggregation: individual sector, industry and aggregate of the economy.[23]

The projections for the PDs pd_t^{big} over the projection horizon, $t = T+1,\ldots,H$, are then obtained using [3], with the financial ratios projected on the basis of [4].

Lastly, the projections for pd_t^{bsg} are adjusted to ensure consistency, for a given size, between the PD projections at the sectoral and the aggregate level, as analysed in the Annex.

4.3 Estimation

Specification [3] is identified separately for each unit (sector, industry, total aggregate) and size with a panel of B banks. $I \cdot G$ models are therefore identified. For a given activity and size, the identification process includes an exhaustive search that

22 This specification does not have bank fixed effects; it is a pooled regression. While the inclusion of fixed effects is advantageous for identification within the sample, it would impose some rigidity on the projections outside the sample in terms of the cross-unit differences that would be detrimental to the main, forward-looking purpose of the exercise. The period is relatively long (20 years) and the specifications implemented are tested to rule out the presence of autocorrelation, thus limiting the undesired effects of not including these fixed effects.

23 Fixed effects are considered for the financial ratio equations, but at sector level rather than at bank level, under the assumption that these invariant average fixed effects will be more stable over time at this higher level of aggregation. As different PD equations are estimated for each sector, in particular with a specific constant, equations [3] and [4] are consistent as regards the level of aggregation for which the fixed effects are considered.

ensures models with significant coefficients, signs consistent with economic theory (e.g. higher PD levels associated with a downturn in GVA growth), a lack of autocorrelation in the residuals and reasonable explanatory power within the sample. Implementing this process results, for each unit and size, in a final specification.

Should the exhaustive search not yield a set of eligible specifications for a unit and size, the model of its associated industry is imputed to it. If no set of eligible specifications for the industry is found, the aggregate model is imputed.[24]

In turn, the identification of [4] is also performed separately, in this case by financial ratio and size, although no exhaustive search is performed. Instead, a manual selection is performed that favours to the extent possible a parsimonious specification with the same characteristics as in the automatic selection applied to [3].

The estimation of [4] is run via OLS. As the specification contains panel fixed effects (sectors) and an auto-regressive component, the estimated coefficients are biased. The typical alternative is the consideration of a GMM estimation method, such as the estimator in Arellano and Bond (1991) or other variants. However, this alternative estimation option requires an additional specification to be selected from within a broad set of instruments. Given the purpose of applying this estimation method on a recurring basis, the set of valid instruments may change over time, rendering the specification less stable. As a result, and since the expected bias induced by the OLS method decreases[25] as the value of T increases, this option is favoured over the GMM estimation. To verify that the bias is not significant vis-à-vis the current sample, the values of the coefficients were cross-checked against those that would be obtained via GMM.

The above-mentioned methodology is implemented with the available sources of information under certain practical considerations. First, a 12-month PD, measured annually, is used. The observation window for the data is 2000-2019, and the projection horizon is three years long.[26] The PD in each observation period for each bank, unit and size is calculated on the basis of the CCR.

In addition to GVA growth, the macro variables considered are 12-month EURIBOR, the unemployment rate, real GDP growth, stock market growth and house price growth. For specification [3] real GDP growth is disregarded, as the correlation between this variable and GVA growth (sectoral variable) may confuse the estimation of the cycle's effect on default risk.

24 This procedure is vulnerable to the situation where there is no eligible specification for the sectoral aggregate either. However, this did not arise in practice. In the imputation the constant is adjusted to ensure consistency in the variables' average.

25 See Nickell (1981).

26 As detailed in Section 3, the baseline scenario reflects a trend path and the others reflect shocks to that path. The years of the exercise's horizon, T+1, T+2 and T+3, are not linked to a specific T.

Three financial ratios, measured in two percentiles (i.e. calculated as a percentile of the sample of firms in each period and for each sector and size) are considered. The three financial ratios are: i) EBITDA plus financial revenue as a percentage of financial costs, proxying the flow of funds generated to service financial costs; ii) ROA; and iii) the ratio of equity to assets. The percentiles are the 50th (median) and the 25th (firms in an unfavourable position). The six financial ratios are calculated using information from the Central Balance Sheet Data Office (CBSO) of the Banco de España, eliminating from the sample those firms without financial debt. It is assumed that, despite not being identical,[27] the populations of the CCR and the CBSO are consistent and that the data from the CBSO are sufficiently representative to indicate the defaults by firms included in the CCR. In order for the inclusion of the financial ratios from the CBSO as explanatory variables to be useful, their average values do not need to be comparable with those of the CCR firms. Instead, a correlation in the financial cycle of the two groups, and that such correlation is not captured by the macroeconomic variables, shall suffice.

The sectoral dimension includes 61 sectors,[28] which approximately represent the two-digit NACE Rev.2 code breakdown, with greater detail in the activities more susceptible to being affected by the green transition. These 61 sectors are grouped into 21 industries.

Business size is broken down into three categories: sole proprietors, SMEs and large firms. Since the CBSO does not have information on sole proprietors, the financial ratios of the SMEs were used as a proxy for their financial position.[29]

5 Findings

The findings yielded by the methodological framework described above are set out in this section. Firstly, Chart 2 shows the differences between each adverse scenario and the baseline in the average projections for ROA over the exercise's three-year time horizon for the corporate sectors most affected by the environmental policy changes under analysis.[30] As expected, the declines are more pronounced in the scenarios combining both effects (higher prices and extended ETS coverage, particularly when they affect households). In the case of SMEs, the greatest

27 The discrepancy is because the universe of firms reporting to the CBSO does not necessarily coincide with the universe of firms that have outstanding bank debt.

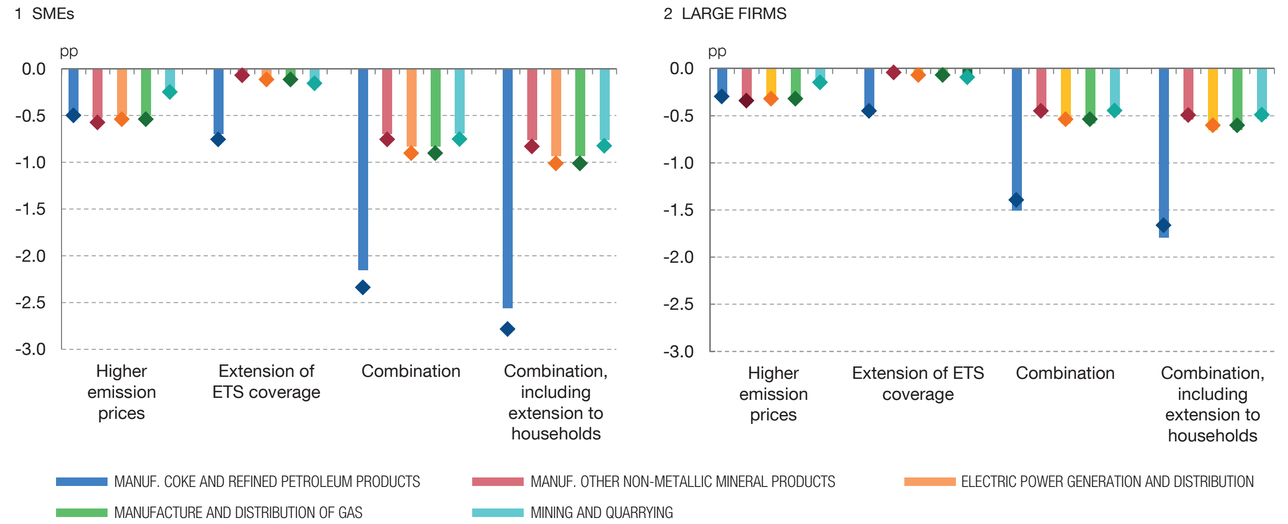
28 While the scenarios are designed for 53 sectors, the FLESB considers 61 sectors to present a more granular breakdown in portfolios with potentially different behaviours in terms of default risk or that are more susceptible to climate-related risks. To do so, the GVA growth paths available from the scenarios are applied to the more granular sectorisation used in the FLESB on the basis of their similar response to the cycle.

29 Should this assumption not be appropriate, the SMEs' financial ratios would generally appear as insignificant in the estimation exercise and would not be used for the final estimation based on the algorithm used.

30 The sectors most affected mean those with the highest PD increase on the baseline under the most adverse scenario. Similar findings for the leverage and interest coverage ratios are available from the authors upon request.

Chart 2

DIFFERENCE IN THE AVERAGE ESTIMATED ROA BETWEEN THE ADVERSE AND BASELINE SCENARIOS (a)



SOURCE: Banco de España.

a The bars represent the estimates for the 50th percentile (median firm), while the diamonds represent the estimates for the 25th percentile (firm facing financial difficulties).

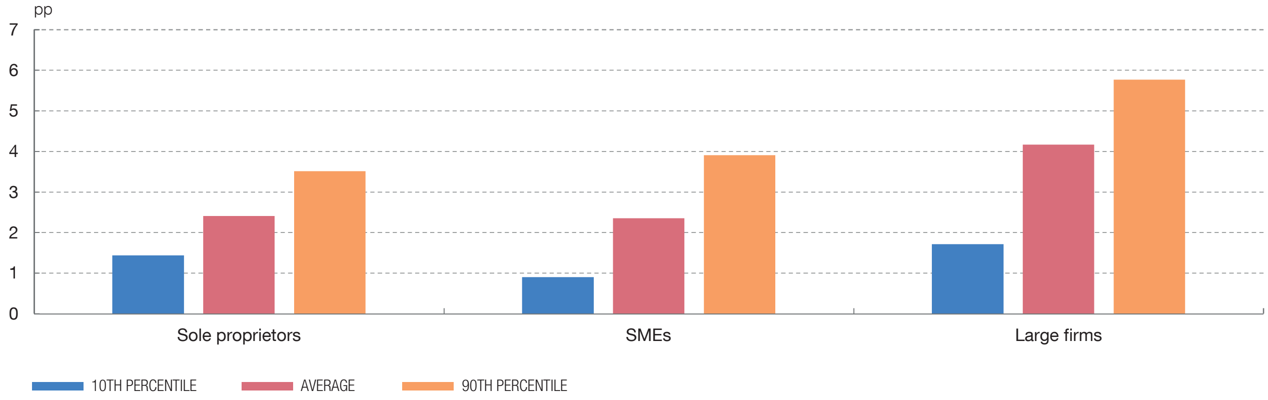
differences compared with the baseline scenario can be found in the manufacture of coke and refined petroleum products (fall of 2.56 pp under the most adverse scenario for the 50th percentile and of 2.78 pp for the 25th), the production and distribution of electricity and gas[31] (0.93 pp for the 50th percentile and 1 pp for the 25th), the manufacture of other non-metallic mineral products (0.77 pp for the 50th percentile and 0.83 pp for the 25th) and, lastly, land transport and transport via pipelines (0.72 pp for the 50th percentile and 0.79 pp for the 25th). In the case of large firms, while the same sectors are affected, the impact is somewhat smaller.

To illustrate the sensitivity of PD to GVA growth on the basis of the estimated models, Chart 3 shows, for each of the three business sizes considered, the average and the 10th and 90th percentiles of the distribution of PD semi-elasticities with respect to GVA growth[32] for the 61 sectors considered. The distributions of semi-elasticities for sole proprietors and SMEs are similar, with average values of 2.41 pp and 2.35 pp, respectively, while that of large firms leans towards somewhat higher values, with an average value of 4.16 pp. The model also includes other explanatory variables (both macroeconomic variables and financial ratios), which are correlated with GVA

31 Both sectors show the same fall since they are assigned similar GVA growth rates in the scenarios. Nonetheless, they are addressed separately for the purposes of the PD projection.

32 Having used a logistic regression, the semi-elasticity of PD to the variable x in point pd^* is given by $\beta\left(1-pd^*\right)$, β being the coefficient of the variable x in the regression. For Chart 3, the average value of the series has been taken as pd^*, and the sum of the contemporaneous coefficients and the first lag as β, and the latter may be equal to 0 depending on the specification chosen.

Chart 3
PD SEMI-ELASTICITIES TO GVA GROWTH



SOURCE: Banco de España.

growth; therefore, the net sensitivity of PDs to the economic cycle must at all times be measured by analysing comprehensive scenarios.[33]

Once the various sectoral PD models have been specified and estimated, these are then used to obtain projections over a three-year horizon in line with the baseline scenario and with the various scenarios involving different extensions of the emissions trading system. Chart 4 shows the deviations in average PD with respect to the baseline scenario over the projection horizon for the five sectors most affected[34] and for all of the sectors in each scenario.

As can be seen in Chart 4, in all of the scenarios in which emission prices rise, the group of sectors with the largest increases in PD is made up of a set of activities with high CO_2 emissions: extractive industries, the manufacture of non-metallic minerals, electricity and gas production and distribution, and the manufacture of coke and refined petroleum products. Where only the extension of the ETS is factored in, certain sectors not previously covered by such system (such as agriculture or certain transportation activities) feature among those most affected. In the scenario in which only a rise in the price of emission allowances is considered, the impact on the PD of the various emissions-intensive sectors is more symmetric, whereas extending the ETS to more sets of sectors, triggering a larger contraction in aggregate demand, gives rise to an outcome with a greater adverse differential effect on petroleum refinery and coke manufacturing and, to a lesser degree, on mining and quarrying and gas production and distribution. In all of the scenarios in which emission prices

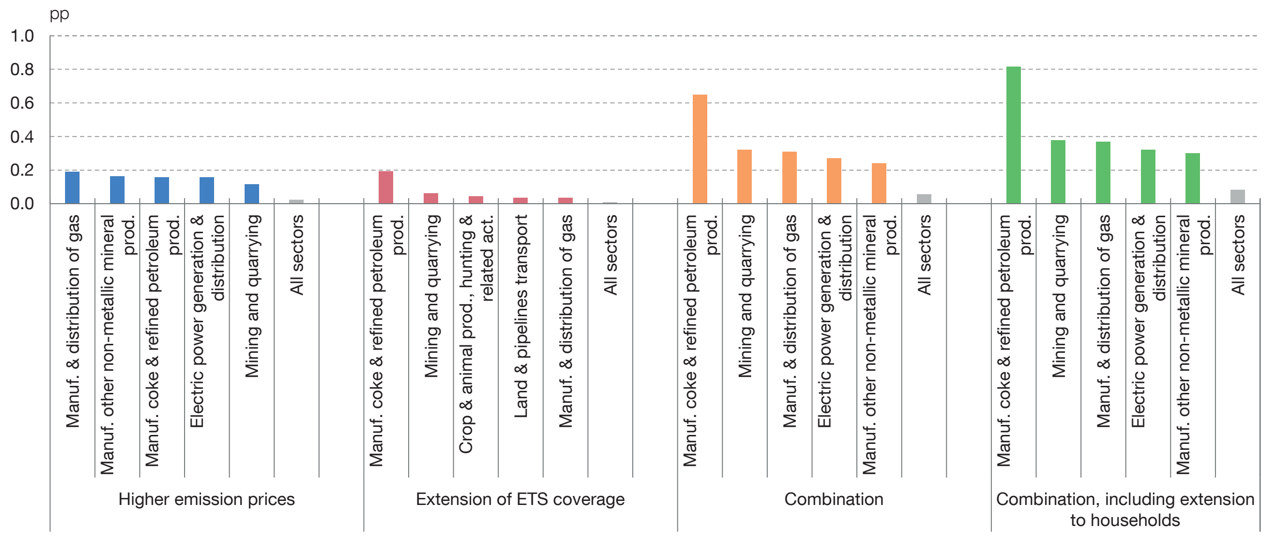
33 It is also worth noting that while these semi-elasticities are seemingly not particularly significant, GVA growth may be very high (even upwards of 10% in absolute terms) and the Logit function is not linear, any changes in PD in the event of changes in GVA growth are material from an economic standpoint.

34 The sectors most affected are those with the highest PD increase with respect to the baseline in the scenarios.

Chart 4

DIFFERENCE IN AVERAGE PDs BETWEEN EACH SCENARIO AND THE BASELINE SCENARIO (a)

1 MOST AFFECTED SECTORS AND TOTAL



SOURCE: Banco de España.

a PD of exposures to large firms, SMEs and sole proprietors. PDs are estimated for each bank, but the average weighted by the number of borrowers is presented.

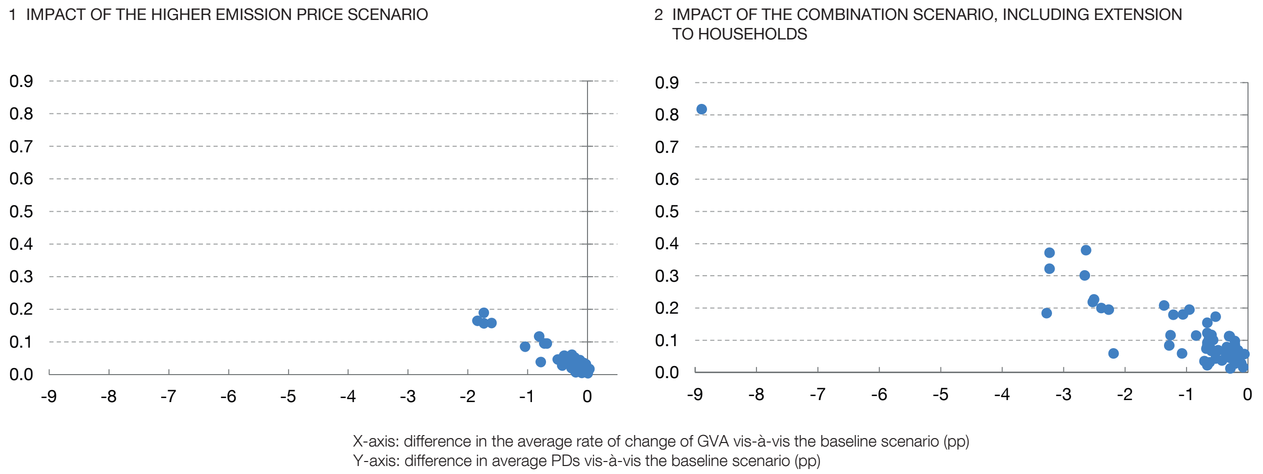
rise, the impact on the PD of these more affected sectors is several orders of magnitude greater than that on the sectors overall. In other words, the sector-specific impact of the various scenarios is highly asymmetric.

As expected, the sectors with larger increases in PD are those with steeper declines in GVA in the scenarios, measuring both aspects against the baseline scenario. Chart 5 shows the correlation between the baseline-adverse scenario differences in respect of PD and GVA growth for the scenario in which emission prices rise (see Chart 5.1), and the scenario combining all effects, including the extension of the ETS to all firms and households (see Chart 5.2). As can be seen in both scenarios, most sectors fall within a limited range of outcomes in terms of GVA and PD, whereas a small group of sectors (CO_2 or other greenhouse gas emissions-intensive sectors or those more sensitive to shocks to activity, such as the real estate sector) suffer greater distress. Particularly worth noting is the point located in the upper left-hand corner of Chart 5.2, which represents the coke manufacturing and oil refinery sector, and shows the greatest average difference in the decline in GVA (-8.9 pp) and in average PD for 2021-2023 (0.82 pp).

Once the PDs have been projected for each scenario and for corporate credit portfolios overall, having regard to their characteristics (sector and business size), the rest of the credit risk parameters required to estimate the expected credit losses on exposures to corporates are estimated: other transition probabilities for stages of credit quality, loss given default (LGD), etc. These other parameters do not depend on activity in the sector, but rather directly on the aggregate macroeconomic

Chart 5

DIFFERENCE IN AVERAGE PDs BETWEEN THE BASELINE AND ADVERSE SCENARIOS AND CHANGES IN GVA UNDER TRANSITION COST SCENARIOS (a)



SOURCE: Banco de España.

a Each dot on the chart represents a sector. PDs are estimated over the projection horizon for each bank, but the difference in each sector's weighted average is depicted. The weighting is done by number of borrowers.

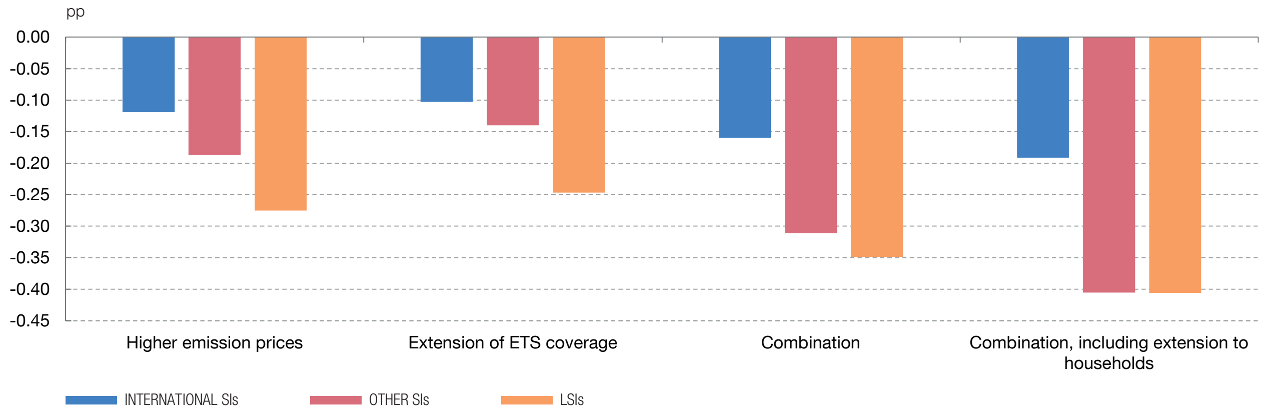
variables (including GDP growth, unemployment and house prices). The credit risk parameters of other (mortgage and consumer) credit portfolios are also estimated, together with other factors contributing to the stress-testing exercise (sovereign exposure risk, generation of net interest income and other income statement items, etc.), as per the standard FLESB procedures.

Thus, the framework enables the net impact of such scenarios on the profitability of Spanish banks to be estimated. Chart 6 shows the differences between the baseline and adverse scenarios in the ratio of accumulated after-tax profit to RWAs for three groups of Spanish institutions: institutions directly supervised by the ECB that have significant international activity (International SIs), the other institutions supervised directly by the ECB (Other SIs) and institutions supervised directly by the Banco de España (LSIs).

The higher emission price scenario has a greater impact than the extended ETS coverage scenario for all groups, in line with the larger increases in PD and the greater worsening of the aggregate macroeconomic forecast associated with the former. In both scenarios, the deterioration is more severe at LSIs and the institutions supervised by the ECB without significant international activity, since the environmental policy changes considered apply only in Spain, while cross-border diversification has a positive effect for the group of International SIs. As expected, the differences are greater (-0.16 pp, -0.31 pp and -0.35 pp for the International SIs, the Other SIs and the LSIs, respectively) in the scenario in which the price effects are

Chart 6

DIFFERENCE IN THE RATIO OF ACCUMULATED AFTER-TAX PROFIT TO RWAs BETWEEN EACH SCENARIO AND THE BASELINE SCENARIO (a) (b)



SOURCE: Banco de España.

a To calculate the ratio, the numerator (profit after tax) is accumulated over the three years of the exercise, while the denominator is the value of average RWAs in the same period.

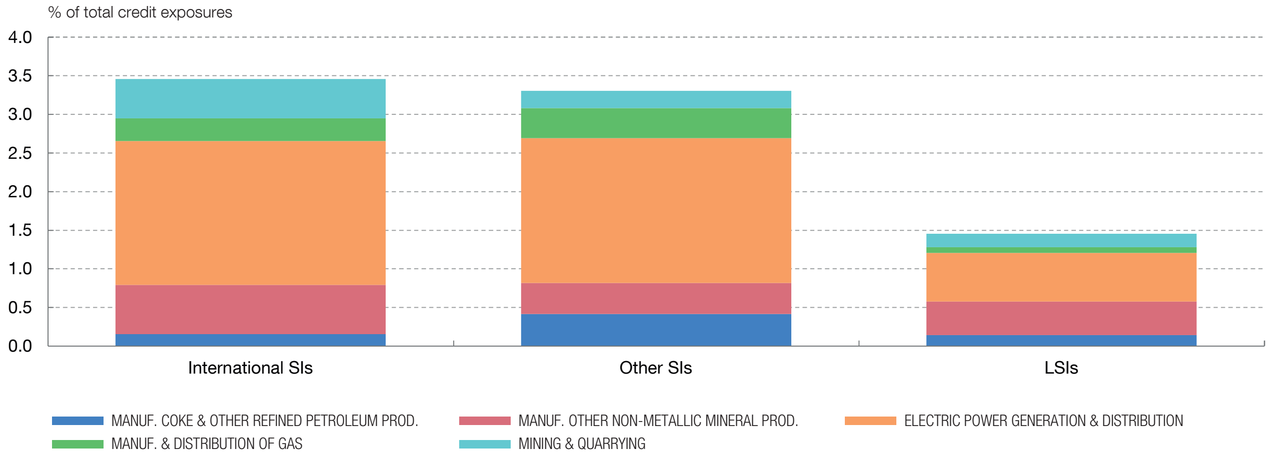
b The chart shows absolute percentage differences vis-à-vis the baseline scenario. However, since the profitability ratio for Other SIs is significantly lower than for the other groups, if the impact were calculated relative to the ratio under the baseline scenario ((adverse ratio - baseline ratio)/baseline ratio), the effect for the Other SI group would be higher than for the other groups. This is linked to the fact that they are not internationally diversified and, compared with LSIs, they are more exposed to the sectors most sensitive to the transition risks considered.

combined with the extension of the ETS to other sectors. Lastly, in the scenario in which ETS coverage is also extended to households, the declines with respect to the baseline scenario stand at -0.19 pp, -0.41 pp and -0.41 pp, respectively.

The impact of these scenarios is, in large part, contained thanks to the fact that the sectoral distribution of Spanish banks' credit exposures to emissions-intensive sectors is limited. Chart 7 shows the five sectors most vulnerable to transition risks (those with the largest baseline-adverse scenario increases in PD in the most severe scenario combining the different policies) as a percentage of the total credit exposures to corporates in Spain for the three groups of institutions analysed above. This percentage ranges from 3.5% for the International SIs to 1.5% for LSIs. Moreover, an analysis of the credit exposures of individual banks does not reveal any significant concentration of exposures to these sectors at any of these institutions.[35] Note that the ultimate impact of the exercise on the solvency of institutions does not depend solely on this sectoral distribution, but rather also on the share of total assets that lending activity accounts for, and the vulnerability of each bank to the shock to the aggregate macroeconomic conditions also entailed by the modification of these policies.

35 For further information on the concentration of Spanish banks in sectors potentially affected by the transition to an emissions-free economy, see Delgado (2019).

Chart 7
SHARE OF SPANISH BANKS' CREDIT EXPOSURES TO SENSITIVE SECTORS (a)



SOURCE: Banco de España.

a Credit exposures in Spain are considered.

6 Conclusions

This article presents the first climate stress test conducted by the Banco de España on all Spanish deposit institutions. The analysis focuses on short-term transition risks arising from environmental policies aimed at reducing CO_2 emissions (higher emission allowance prices and extension of their requirement to more sectors) and their uneven impact on the different economic sectors. Both components have been included in the Banco de España's top-down FLESB stress-testing tool. To this end, macroeconomic scenarios reflecting these transition risks, developed with the Banco de España's CATS model, have been applied, and the FLESB credit risk methodology has been extended to enable PDs to be modelled with a high sectoral granularity, with sensitivity to GVA growth and to the financial position of firms in different economic sectors. These innovations are useful for credit risk modelling under general crisis scenarios, not just those linked to climate risks.

The exercise shows that the short-term impacts of the transition scenarios on the profitability and solvency of the Spanish banking sector are moderate, although the impact on PD and financial position is uneven across sectors. In particular, the sectors most linked to greenhouse gas emissions would be the most affected. However, these exposures represent a very limited fraction of total bank lending to business activity in Spain. Spanish banks would, therefore, be able to absorb the materialisation of the short-term transition risks envisaged in this exercise, which focus on shocks to the activity of the different economic sectors.

This exercise should be understood as a first milestone in climate risk quantification by the Banco de España. Future research will analyse the modelling of physical risks (desertification, floods, fires, etc.) in the macroeconomic environment and the banking sector, and additional risks from the transition to a green economy, such as those arising from replacing productive capital to adopt new technologies or the effects of the higher cost of emission allowances on prices.

Lastly, it should be noted that exercises of this kind are useful for informing monetary policy decisions. Although climate change and its economic and physical consequences go beyond the strict scope of the banking sector, and despite the fact that this first exercise examines only a limited subset of the total exposures, the analysis conducted helps to reduce uncertainty surrounding the effect of policies to combat climate change. Finding that certain transition risks will have a limited impact provides information, albeit still partial, for the cost-benefit assessment of adopting measures and allows future research to be steered towards other sources of transition and physical risks.

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The projections for pd_t^{bsg} are adjusted to ensure consistency, for a given size, between the PD projections at the sectoral and the aggregate level. This requires, for a given size and for each period of the projection horizon, the weighted average of the PDs of the S sectors in the B banks to be equal to the aggregate PD for that size. In other words, the following must be satisfied:

$$\sum_{s,b=1}^{S,B} m_T^{bsg} pd_t^{bsg} = pd_t^{ag} \qquad [A.1]$$

for each period $t = T+1, \ldots, H$ and each size $g = 1, \ldots, G$, where m_T^{bsg} is the number of debtors of bank b, in sector s, in size g, in the latest observation period T.[1]

Since the proposed framework does not guarantee that condition [A.1] is met when projecting sectoral and aggregate PDs separately, this condition is imposed by means of a positive scalar for each size and time period of the projection horizon, k_t^g, which multiplies the PD projections for all banks and sectors obtained from the disaggregated model. It is therefore a linear scaling. Coefficient k_t^g is calibrated to satisfy equation [A.1].

The final projection, $\dot{pd}_t^{bsg}$, $t = T+1, \ldots, H$, is thus calculated as:

$$\dot{pd}_t^{bsg} = k_t^g pd_t^{bsg} \qquad [A.2]$$

This adjustment allows the final projection for each bank to be interpreted as the aggregation of two effects: the systemic changes in PD by firm size and the dispersion of PD across economic sectors. Adjusting for the aggregate of banks rather than on a bank-by-bank basis ensures that the different sectoral composition of their portfolios is reflected in the estimate. If the adjustment were made bank by bank, the aggregate PD for the size would result from the aggregate model, and would therefore be insensitive to the bank's sectoral composition. Conversely, by adjusting at the aggregate level, if a bank, for example, has a higher concentration than the system aggregate in sectors with higher PD projections (because it is more sensitive to the climate scenario), then its aggregate PD by firm size will also tend to be greater than that of the system as a whole.

1 The weighting by the number of debtors in each sector is kept constant over time because of the high computational cost of recalculating their number in each period and their relative stability within the projection horizon.