BANCA D'ITALIA

EUROSISTEMA

Mercati, infrastrutture, sistemi di pagamento

(Markets, Infrastructures, Payment Systems)

Assessing credit risk sensitivity to climate and energy shocks

by Stefano Di Virgilio, Ivan Faiella, Alessandro Mistretta
and Simone Narizzano

September 2023

Number 41

BANCA D'ITALIA
EUROSISTEMA

Mercati, infrastrutture, sistemi di pagamento

(Markets, Infrastructures, Payment Systems)

Assessing credit risk sensitivity to climate and energy shocks

by Stefano Di Virgilio, Ivan Faiella, Alessandro Mistretta
and Simone Narizzano

Number 41 – September 2023

The papers published in the 'Markets, Infrastructures, Payment Systems' series provide information and analysis on aspects regarding the institutional duties of the Bank of Italy in relation to the monitoring of financial markets and payment systems and the development and management of the corresponding infrastructures in order to foster a better understanding of these issues and stimulate discussion among institutions, economic actors and citizens.

The views expressed in the papers are those of the authors and do not necessarily reflect those of the Bank of Italy.

The series is available online at www.bancaditalia.it.

Printed copies can be requested from the Paolo Baffi Library: richieste.pubblicazioni@bancaditalia.it.

ISSN 2724-6418 (online)
ISSN 2724-640X (print)

Banca d'Italia
Via Nazionale, 91 - 00184 Rome - Italy
+39 06 47921

Designed and printing by the Printing and Publishing Division of the Bank of Italy

Assessing credit risk sensitivity to climate and energy shocks

by Stefano Di Virgilio,* Ivan Faiella,** Alessandro Mistretta,**
and Simone Narizzano*

Abstract

We apply a novel method to estimate the impact of a change in energy expenditure on Italian firms' credit risk, measured as the 12-month default probability (PD). We examine a shock to energy expenditure originating from different carbon tax levels and then 1) shock energy prices; 2) re-compute the firm-level energy mix; 3) assess the impact on the firm PD via the re-calculation of its financial statement. The flexibility of this approach, which includes scope 2 emissions, enables us to assess the transmission channels of energy shocks and firm exposure in detail. Our results show that the introduction of carbon taxation would have a limited impact on credit risk: a carbon tax of EUR 40, EUR 90 and EUR 140 per tonne of CO2 would raise the average PD by 0.6, 2.3 and 4.1 basis points, respectively. The effect is slightly larger for the Agriculture and Services sectors, while there is no clear pattern relating to firm size.

JEL Classification: Q41, Q54, Q58.
Keywords: climate change, carbon tax, credit risk.

Sintesi

Il lavoro applica una nuova metodologia per stimare gli effetti di un aumento della spesa energetica sul rischio di credito delle imprese italiane, misurato dalla probabilità di insolvenza a 12 mesi (PD). Nel dettaglio, ipotizziamo l'introduzione di differenti livelli di carbon tax e, conseguentemente: 1) stressiamo i prezzi energetici; 2) ristimiamo la domanda di energia delle imprese; 3) valutiamo gli effetti sulla PD delle imprese attraverso il ricalcolo del bilancio aziendale. La flessibilità dell'approccio, che include l'analisi delle emissioni scope 2, ci consente di valutare in dettaglio il canale di trasmissione degli shock energetici e la contestuale esposizione delle imprese. I nostri risultati mostrano che l'introduzione di una carbon tax avrebbe effetti mediamente contenuti sul rischio di credito: una carbon tax di EUR 40, EUR 90 e EUR 140 per tonnellata di CO2 aumenterebbe la PD media di 0,6, 2,3 e 4,1 punti base, rispettivamente. L'effetto è lievemente maggiore per il settore dell'agricoltura e dei servizi mentre non si rilevano effetti chiari considerando la dimensione aziendale.

* Bank of Italy, Financial Risk Management Directorate.
** Bank of Italy, Secretariat to the Governing Board.

CONTENTS

1. Introduction[1]

This paper applies a novel method to estimate the impact of a change in energy expenditure on Italian firms' credit risk, measured as the 12-month probability of default (PD). In particular, we examine a shock to energy cost originating from different levels of a carbon tax and then 1) shock energy prices; 2) re-compute the firm-level energy mix; 3) assess the impact on the firm PD via the re-calculation of its financial statement, which is the key input for credit risk assessment. This study is part of a broader effort within the Bank of Italy to define the impact of transition policies on corporate performance. The impact of climate policies on credit risk has some similarity with that of the energy market disruptions that firms and households have experienced since the second half of 2021.

Climate change poses a threat to economic activity via several channels, e.g. owing to reduced labour and energy productivity; some extreme weather events have also drove down short-term economic growth (IPCC, 2022). The biggest threat is for the most climate-exposed sectors such as agriculture, forestry, fishery, energy, and tourism. Climate change has an impact on financial institutions as well (e.g. de Guindos, 2021). The risks for the stability of the financial system will also depend on the climate policies and on the exposure of the different sectors of the economy to such policies.

Climate-change effects may spread to the financial sector in several ways. Natural disasters, by disrupting the activities of companies and households, raise their financial vulnerability and lower the value of the collateral pledged for loans. Repaying loans may become more complex due to the diversion of resources for restoring damaged property. Environmental shocks may increase the number of non-performing loans in the portfolio of those banks that are particularly exposed to households and businesses in the areas most at risk. This could induce banks to restrict the supply of credit, which would potentially affect the effectiveness of the credit channel of monetary policy. If these effects occurred on a large scale, they might threaten the stability of the financial system as a whole (Faiella and Malvolti, 2020).

In the future, climate-related credit risk management will increasingly be a key element for successful banks, that will enable them to assess the impact of climate on the borrowers' ability to repay their loans. The estimation of these risks, however, is a challenging task because the impacts of future climate manifestations will be highly uncertain, non-linear and largely endogenous (Monasterolo, 2020). The evaluation of these risks at individual firm level is made even more challenging due to the lack of detailed and comparable data on the exact geographical location and on the carbon intensity of individual activities (FSB, 2021).

Public and private institutions, central banks and supervisors are promoting joint efforts to assess the possible implications of climate policies on the economy and the financial sector. Central banks are well positioned to assess the threat posed by climate change on the financial system. At the end of 2017 the growing awareness of these issues led to the creation of the

[1] We would like to thank the participants to the Workshop on Climate change risk and credit assessment. We are also indebted to Antonio Scalia and Alessandra Iannamorelli for the useful comments and suggestions. The opinions expressed and conclusions drawn are those of the authors and do not necessarily reflect the views of the Bank of Italy; all errors remain under our responsibility.

Network for Greening the Financial System (NGFS), a global network of central banks and supervisory authorities that promotes the sharing of experiences and best practices concerning the management of environmental risks in the financial sector, focusing specifically on climate risks. The NGFS found that 'climate- or environmental-related criteria are not yet sufficiently accounted for in internal credit assessments or in […] credit agencies' models' (NGFS, 2018). More recently, the NGFS has published two documents to help central banks and financial regulators in assessing climate risks. The first (NGFS, 2022a) provides an update on existing analyses and practices on the methodologies used by financial institutions, credit rating agencies (CRAs) and supervisors to assess and quantify climate-relate financial risk. The second document (NGFS, 2022b) examines how CRAs integrate climate-related risks in their assessments.

There have been several attempts to assess how climate risks may affect credit risk differentials. Climate policies, either indirectly through regulation or directly via carbon pricing, increase firms' energy costs – at least in the short and medium-term – possibly impairing the ability to repay their debt. The flexibility of our approach, which includes scope 2 emissions, enables us to assess the transmission channels of energy shocks and the firm exposure in detail.

The paper is organized as follows. Section 2 quickly reviews the literature on the relationship between climate change and credit risk and introduces the contribution of our approach. Section 3 describes the dataset for the empirical analysis. Section 4 introduces the in-house credit assessment system of the Bank of Italy (BI-ICAS). Section 5 presents the main elements of our simulation and Section 6 gives the results. Section 7 concludes.

2. The relationship between climate change and credit risk

The literature on the impact of climate change on credit risk obtains mixed results. Capasso *et al.* (2020) find that the distance-to-default is negatively associated with firm's carbon emissions and carbon intensity. Balasirishwaron *et al.* (2022), using an Ordered Probit approach for credit analysis which includes the issuer ESG status and credit ratings, find a low correlation but some common factors driving credit and ESG ratings. They suggest that, in a diversified bank portfolio, ESG and credit factors could jointly boost overall risk through their positive correlation.

More recently, a series of studies at the Bank of Italy have analyzed the possible impact of climate transition risk on financial fragility and sectoral PDs. Faiella *et al.* (2022) use granular data at the counterparty level to estimate the impact of alternative carbon tax levels on energy demand and costs, thus identifying the most financially vulnerable sectors. Aiello and Angelico (2022), building on the previous work, estimate the impact in terms of default rates at the sector level; they find that credit risk stemming from the introduction of a carbon tax raises the one-year PD of firms but it remains below the historical average.[2]

In this study, we extend the above analyses to firm-level PD information using the in-house credit assessment system of the Bank of Italy (henceforth BI-ICAS). This model has been developed

[2] They use data from March 2006 to December 2019.

since 2013 to enable Italian banks to use the loans granted to non-financial firms as collateral in Eurosystem monetary policy operations.[3] The model has two components: i) the statistical component, with an extremely wide coverage of Italian non-financial companies; ii) the expert component, which applies to a subsample of companies. The statistical component is a highly automated system which produces an estimate of the probability of default (Statistical PD) for Italian non-financial corporations on a monthly basis.

Using the methodology developed in Faiella *et al.* (2022), we simulate the detailed energy expenditure of each firm and employ an estimate of the additional cost due to the effect of different levels of carbon tax on operating costs in the financial statement of each firm. These values are then used as an input for BI-ICAS to calculate the stressed 12-month PD. The flexibility of this approach enables us to assess the channels and the exposure with greater detail compared to the existing studies. We also cover the exposure of the firm in terms of scope 2 emissions, that we implicitly consider because we have a complete picture of each firm's energy mix. This approach is not limited to climate policy shocks, but it can be used to assess how other types of climate and energy shocks might affect credit risk.

3. Data

Our approach integrates a new dataset on firm-level costs with the information routinely used to estimate the PD in the BI-ICAS model. Following the approach of Faiella *et al.* (2022), the new dataset includes the sector-level fuel-specific use per employee together with data on employees and other financial information at firm-level.

Information on the PD – Statistical PDs produced with the BI-ICAS model mainly rely on two types of information: 1) credit behaviour data, collected by the Bank of Italy in the National Credit Register (NCR); 2) financial statements collected by Cerved Group.

The NCR is a national archive of banks' and financial intermediaries' debtors. On a monthly basis, all banks and other financial intermediaries are required to send to the NCR a wide set of information about the financial liabilities and payment behaviour of individual entities (companies and households). In return, banks have access to information on the debt exposure of their borrowers towards the whole banking system. The NCR is extremely accurate, as it collects information about all credit relationships with a minimum size of EUR 30,000.

The model relies on the Bank of Italy's financial statement archive (*Sistema informativo economico-finanziario*, SIEF) based on data collected from the Cerved Group. Such data are available in two separate datasets:[4] Cebi (from Centrale dei Bilanci) and Cerved. The Cebi dataset contains around 80,000 financial statements per year covering nearly all the medium and large firms and about half of the small ones. These data are collected partly through banks participating

[3] The definition of default used by BI-ICAS was approved by the Eurosystem and is consistent with the definition given in the Basel Accords.

[4] Financial statement data are available according to the Cebi reclassification accounting scheme, which can be applied to both the national GAAP and IFRS financial statements.

in the Cebi program and for the rest through the Official Business Register. Cerved is a more comprehensive dataset of the Italian corporate sector, including also nearly all the small and micro limited-liability companies. Data are provided by the National Official Business Register.

The analysis covers more than 200,000 limited liability firms, representing about 60 per cent of all joint-stock company revenues. From an industry perspective, more than half of the companies belong to the Services sector, while the second largest sector is Manufacturing.[5] Construction and Agriculture have the highest average PD, with a right-skewed distribution (Table 1).

Table 1 – Baseline PDs by sector (percentage points)

Sector	**Mean**	**5th percentile**	**Q1**	**Q2**	**Q3**	**95th percentile**	**Number of firms**
Agriculture	3.5	0.1	0.5	1.2	3.0	9.3	2,084
Construction	3.6	0.1	0.3	0.8	2.3	11.2	25,856
Manufacturing	1.9	0.0	0.2	0.5	1.2	5.5	61,872
Services	2.4	0.1	0.3	0.8	1.9	6.6	116,065
Entire sample	2.4	0.1	0.3	0.7	1.7	6.8	205,877

The PD pattern by size[6] reflects the large number of micro and small firms operating in Italy. The micro companies represent more than half of the total number of firms and exhibit slightly higher PDs (Table 2).

Table 2 – Baseline PDs by size (percentage points)

Size	**Mean**	**5th percentile**	**Q1**	**Q2**	**Q3**	**95th percentile**	**Number of firms**
Micro	2.5	0.1	0.3	0.8	1.9	7.0	117,900
Small	2.3	0.0	0.2	0.6	1.5	6.7	66,603
Medium	2.2	0.0	0.2	0.5	1.3	6.4	17,151
Large	2.0	0.0	0.2	0.6	1.5	6.7	4,223
Entire sample	2.4	0.1	0.3	0.7	1.7	6.8	205,877

Energy expenditure - Energy costs are a relevant, although sometimes neglected, driver of firm performance. According to Faiella and Mistretta (2015), the energy expenditure of the Italian manufacturing sector is equivalent to about 2.4 per cent of total sales and energy plays a key role in business decisions, such as the propensity to export. Faiella and Mistretta (2022) find that the purchase of energy is a key factor also at the European level: over the last decades the energy cost

[5] Firms operating in the Mining and Utilities sectors have been excluded from the analysis considering the limited number of observations in our sample.

[6] The size is based on total assets, turnover and number of employees (according to the European recommendation 2003/361/EC).

has steadily increased, becoming equivalent to about one third of total labor cost. The boldest decarbonization targets will involve a further increase in energy prices (e.g. for the extra-costs of a full-fledged EU ETS or the introduction of an EU-wide carbon tax of non-ETS emissions). These added costs may have a detrimental effect on industry competitiveness and on the individual firm's ability to honor its debt, thus providing a material example of transition risk. Despite the relevance of this issue, European statistics on energy costs are scant, irregular and with a very limited level of disaggregation. To close this information gap we impute energy expenditure integrating balance sheets information from Cerved Group with information on employment at the firm level using data from the National retirement planning agency (INPS) and the industry-level statistics provided through the Physical energy flow accounts (PEFAs). We use the information on per-worker energy consumption (using total workers data provided in the National Accounts) and on different energy sources at sector-level;[7] in addition we use firm-level employee data to obtain the firm-level estimate of energy use. This method implies that within-sector variability depends only on the number of workers. A check of this approach with external sources shows that our estimates provide a fair picture of firms' energy consumption (for further details see Appendix B in Faiella *et al.*, 2022). The energy use in physical terms is then multiplied by fuel-specific energy prices (from Eurostat and the Ministry of economic development) to obtain the energy expenditure for each firm in the sample.

4. The BI-ICAS model

Since 2013 the Bank of Italy has developed the BI-ICAS model, for assessing the creditworthiness of Italian non-financial corporations, to be used in the context of the Eurosystem Credit Assessment Framework (ECAF).[8] ECAF defines the minimum credit quality requirements as well as the rules and procedures which ensure that the Eurosystem only accepts adequate collateral, as required by article 18.1 of the Protocol on the Statute of the European System of Central Banks and of the European Central Bank.

BI-ICAS plays a key role in monetary policy operations since it allows all Italian counterparties to pledge credit claims to non-financial corporations as collateral. In particular, ICAS can be used by small and medium-sized banks that do not have an internal rating system and are not in a position to easily fund themselves through structured finance operations, such as asset-backed securities or covered bonds. The development of BI-ICAS has contributed to increase collateral availability for a wide range of Italian counterparties with different business models, thus paving the way for a smooth implementation of monetary policy.[9]

The BI-ICAS rating process is based on a two-stage procedure to assign a rating (Giovannelli *et al.*, 2020). The first stage involves the use of a statistical model, is based on hard data and is largely automated; the second stage is an expert assessment made by at least two financial analysts using

[7] We use PEFA information for 6 fuels (gas, power, renewables, coal, oil products and heat) and 74 sectors for 2019.

[8] https://www.ecb.europa.eu/paym/coll/risk/ecaf/html/index.en.html

[9] The BI-ICAS statistical model produces, every month with a fully automated procedure, a PD for around 350,000 Italian limited-liability non-financial companies.

also qualitative information. At the end of the second stage, analysts can either confirm or modify the rating derived from the statistical model. Overall, the expert assessment performs a review of the output of the statistical model based on a larger set of key risk drivers. However, the expert assessment is only performed for a subsample of firms for which a statistical assessment is available, in the order of 4,000 companies every year.[10]

The statistical model consists of a system of logistic regressions and produces a one-year PD for all Italian limited liability non-financial companies having both an available financial statement and an exposure towards the financial system of at least 30,000 euro, as reported in the National Credit Register (NCR).

The statistical model, consisting of multiple statistical sub-models, has two independent components providing distinct credit scores, each representing partial measures of credit risk:

- the credit behaviour sub-model employs a logit regression with data from the NCR and models the credit relationship among the companies and the banking system. Three different sub-models are set up for different firm classes according to their financial debt exposure (small companies with exposure below EUR 300,000; medium companies with exposure between EUR 300,000 and 20 million; and large companies with exposures exceeding EUR 20 million);
- the financial sub-model employs a logit regression based on yearly financial statement data, such as the debt-sustainability ratio, financial structure and liquidity ratios. The financial component consists of sub-models separately estimated for each of six different sectors (Manufacturing, Trade, Construction, Services, Real estate and Holdings[11]).

The results of these two exercises are then merged into the final model through an additional logistic regression that provides the final score, which is then transformed into a PD via the inverse logit function.

5. Simulation

In this section we present the assumptions underlying our exercise to assess the impact of a climate policy shock on firm PDs. We use 2019 fiscal year financial statement data[12] for approximately 200,000 Italian non-financial limited-liability companies. We simulate the effects of three possible carbon taxes that are consistent with the trajectories of the following three NGFS scenarios: *Below 2°C* (EUR 40 per tonne of CO_2[13]), *Net Zero 2050* (EUR 90) and *Delayed Transition*[14]

[10] This subsample covers a large share of the credit claims pledged as collateral by banks using BI-ICAS.

[11] Real estate and Holding companies are not included in our sample.

[12] The 2020 fiscal year financial statement data were not considered in the analysis because of the Covid-19 pandemic and the related extraordinary measures (e.g. government firms' support).

[13] To put things into perspective, consider that Introducing a carbon tax of EUR 50 per tonne is equivalent to increase energy costs as follows (values in EUR 2015): +EUR 0.014 per kWh for electricity, + EUR 2.8 per GJ for gas and +EUR 0.12 per litre for liquid fuels (see Faiella and Lavecchia, 2021).

[14] We assume that the carbon tax implied in different scenarios is implemented immediately.

(EUR 140). We assume a one-off introduction of the taxation on final energy use on top of existing taxes on energy (and costs levied as part of the EU-ETS). A carbon tax is often used as a climate policy shocks: due to its effectiveness in adjusting the (mis)pricing of climate risks and in providing an incentive to move away from fossil-fuels; but its simplicity is counterbalanced by its low social acceptability (Jagers *et al.*, 2021). However, a change in the relative price among different energy fuels might arise from other drivers, such as a ban on a specific type of carbon-intensive technology (e.g. Internal combustion engine cars) or the support for low-carbon energy sources.

The climate shock in all these different scenarios can be modelled as an increase in the price of fossil-based energy services, whose extent changes with the carbon content of different energy fuels. We use the approach of Faiella and Lavecchia (2021) and Faiella *et al.* (2022), who translate the impact of each carbon tax on final energy prices applying the specific carbon emission factors for each fuel source (Table 3).

Table 3 – Carbon tax effect on different energy prices (€ 2015 and p.p.)

Carbon tax	**Power**		**Gas**		**Gasoil**	
€/ton	€/toe	%	€/toe	%	€/toe	%
40	124.6	6.6	90.6	23.5	110.9	11.2
90	280.4	14.9	203.9	53.0	249.5	25.2
140	436.2	23.1	317.2	82.4	388.2	39.2

* Percentage changes compared with 2019 average prices; toe stands for ton of oil equivalent, i.e. the quantity of energy contained in a ton of crude oil.

We assess the effects of these changes on energy expenditure and firms' EBITDA computing the price increase caused by the introduction of a carbon tax on the firms' energy use and expenditure, using the estimates of Faiella *et al.* (2022).[15] We thus compute the additional cost that each firm in our sample should bear and we can recalculate all the impacted income statement variables, such as value added, EBITDA, EBIT and net income (NI). For instance, the new value of EBITDA for firm *i* with a carbon tax *c* is calculated as follows:

$$EBITDA_{i,c} = EBITDA_{i,2019} - AC_{i,c},$$

where $EBITDA_{i,2019}$ is the initial value and $AC_{i,c}$ is the additional cost that should be borne by firm *i* with a carbon taxation equal to *c.*

When assessing the impact on the net income variable, we must take into account the reduction in taxation:

[15] The dependent variable is firm energy demand and the explanatory variable are the energy prices and a set of additional controls, such as information regarding firms' energy efficiency, its market power, its value added, and the share of renewable sources in its energy mix.

$$NI_{i,c} = NI_{i,2019} - \left[AC_{i,c} * (1-\tau)\right],$$

where τ is the corporate tax rate.[16]

After the recalculation of the income statement, it is possible to re-compute the balance sheet variables. For the accounting principle, the impact on equity (E) is equal to the difference estimated for net income:

$$E_{i,c} = E_{i,2019} - \left[AC_{i,c} * (1-\tau)\right]$$

We also take into account a reduction in liquidity due to the carbon tax. If the impact of the carbon tax cannot be entirely absorbed by the initial value of liquidity, the remaining part is covered by an increase in the firm's short-term financial debt.[17] Recalculations of assets and liabilities follow directly.

The results of the financial statement recalculations are used as input to the statistical BI-ICAS model to assess the effect of the carbon tax on the PD of Italian non-financial companies.

6. Results

In this section we report the main results in terms of the impact of the three possible levels of carbon tax on the one-year statistical PDs of the firms in our sample. The results are presented in terms of deviation from the current baseline without carbon tax.

On average, the effect of a carbon tax on the credit-worthiness of Italian non-financial corporations would be contained and diversified across industrial sectors. When considering the total economy, the average PD in the three different scenarios (carbon tax of EUR 40, EUR 90 and EUR 140) would increase respectively by 0.6, 2.3 and 4.1 basis points. On the one hand, the higher the increase in energy costs the higher is the relative impact on companies' operating margin and leverage and, consequently, the effect on PDs is increasing and non-linear. On the other hand, firms' energy demand elasticity compensates this effect but not entirely. As in Aiello and Angelico (2022), the average increase on the PDs is heterogeneous across different economic sectors, with Agriculture and Services being the most exposed considering both the energy consumption and the low reactivity to change in energy prices[18] (Faiella *et al.*, 2022) (Table 4).

[16] In Italy, the corporate tax rate 24% (IRES, *imposta sul reddito delle persone fisiche*). There is also an additional 3.9% regional tax on productive activities (IRAP, *imposta regionale sulle attività produttive*).

[17] We assume a maximum reduction of liquidity equal to 90 per cent of the initial value. This hypothesis derives from the fact that firms prefer, whenever possible, to keep a minimum amount of liquidity for operating needs (De Socio *et al.*, 2020).

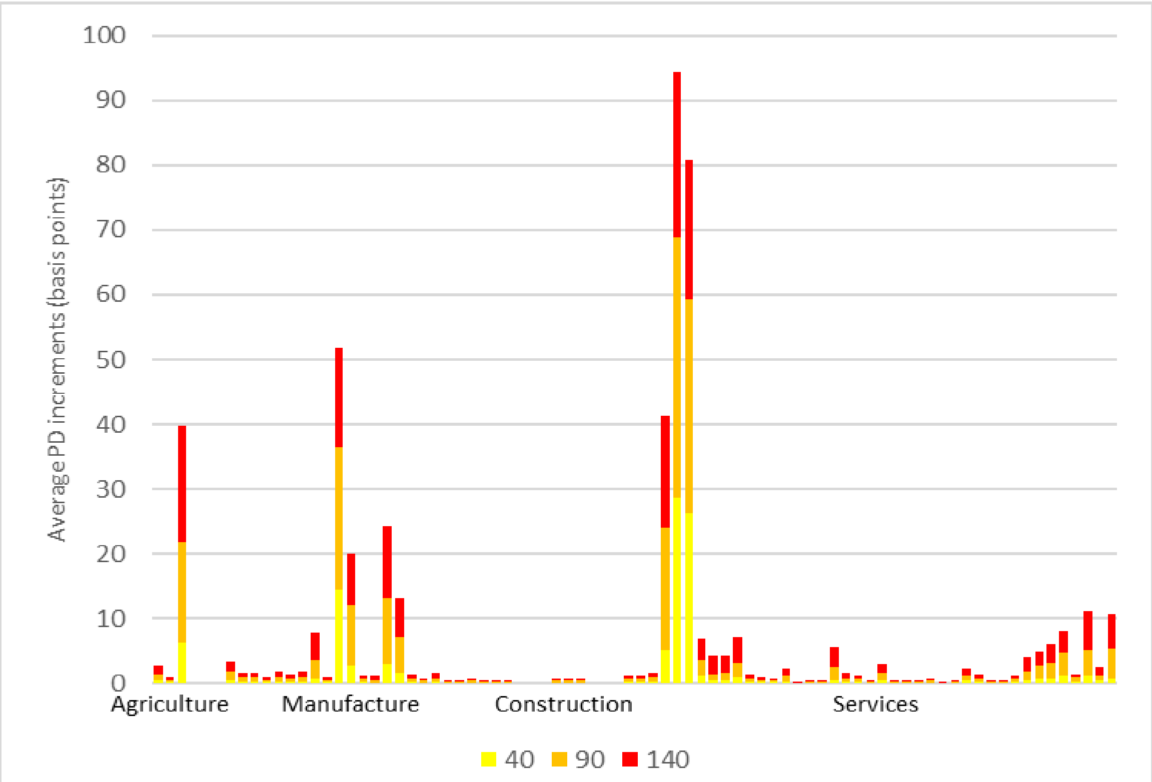
[18] Firms' energy demand elasticity depends on their capacity to adjust their energy mix towards less expensive and low carbon energy sources.

Table 4 - Average PD increments by sector (basis points)

Sector	Carbon tax			Number of firms
	€ 40	*€ 90*	*€ 140*	
Agriculture	0.8	2.7	5.0	2,084
Construction	0.1	0.4	0.7	25,856
Manufacturing	0.4	1.8	3.3	61,872
Services	0.7	2.9	5.3	116,065
Entire sample	0.6	2.3	4.1	205,877

A more granular analysis gives some further insight on the heterogeneity of exposure to transition risks of the industries classified within the same sector. Looking at the detailed effects of the increase in carbon taxation for each NACE 2-digit division (Figure 1), we find that all sectors, excluding Construction, show a high dispersion of average PD increments (see Appendix A for further details). The high level of within-sector variability suggests, as already pointed out by other studies (such as Allen *et al.*, 2020), that more granular analyses at sector level would provide a more accurate assessment of environmental risk.

Figure 1 - Average PD increments by NACE division (basis points)



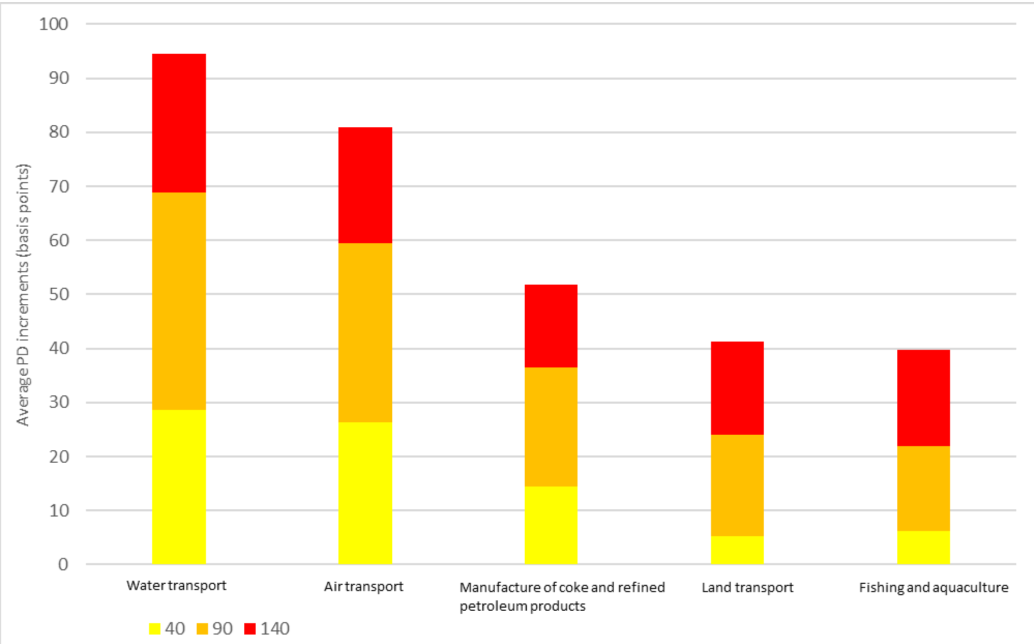
According to our results, the five most exposed industries are (Figure 2):

- Water transport (NACE 50);
- Air transport (NACE 51);
- Petrochemical: manufacture of coke and refined petroleum products (NACE 19);
- Land transport and transport via pipelines (NACE 49);
- Fishing and aquaculture (NACE 3).

Unsurprisingly, among the most exposed industries, we find sectors with a very high dependence on fossil fuels such as the Petrochemical sector and/or sectors with an inelastic energy demand (a proxy of their possibility to switch to a greener energy mix), such as Water transport and Air transport.

For these sectors, the introduction of a EUR 40 carbon tax increases the PDs in the range between 5.2 (Land transport) and 28.7 basis points (Water transport) and the highest carbon tax would worsen the credit worthiness by between 39.8 (Fishing) and 94.4 basis points (Water transport).

Figure 2 – Most impacted NACE divisions, average PD increments (basis points)

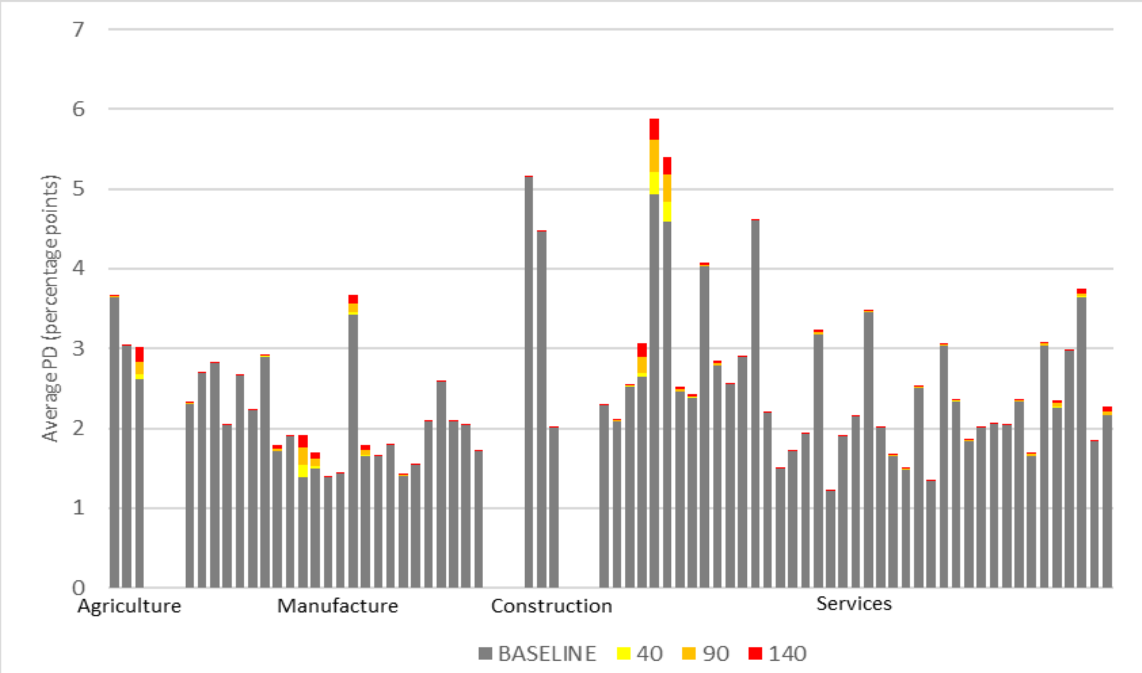


As a robustness check, we replicate our estimates on 2018 data and we do not find any significant difference (the results are available in the Appendix A).

Our findings are broadly consistent with the results of Vermeulen *et al.* (2018) and Allen *et al.* (2020), who find that the Transportation and Petrochemical sectors are among the high-risk sectors.

Considering the relevant increase of the PDs compared to the baseline, with a EUR 140 carbon tax, Air and Water transports would become the sectors with the largest average PD (Figure 3).

Figure 3 - Average PD by sector (percentage points)



Looking at different firm size, we do not detect any clear pattern in terms of average PD increase (Table 5).

Table 5 - Average PD increments by dimensional class (basis points)

Size	**Carbon tax**			**Number of firms**
	€ 40	*€ 90*	*€ 140*	
Micro	0.5	2.2	4.0	117,900
Small	0.6	2.4	4.4	66,603
Medium	0.7	2.4	4.0	17,151
Large	0.5	1.8	3.2	4,223
Entire sample	0.6	2.3	4.1	205,877

7. Conclusions

In this paper we propose a novel method to correlate the change in energy expenditure with the individual firm probability of default, drawing from the methodology developed in Faiella *et al.* (2022) and employing the internal credit assessment model of the Bank of Italy (BI-ICAS).

In particular, we hypothesize the introduction of a carbon tax at different levels, used as a possible innovation in climate policy in Italy, and simulate the energy expenditure of each firm. These values are then used as input for the BI-ICAS model to calculate the stressed 12-month PDs.

This approach also covers the firm exposure in terms of scope 2 emissions, since we have a complete picture of each firm's energy mix. This approach may have further uses, since it allows us to assess how the developments of climate change and energy prices may affect credit risk.

The results show that the impact of the introduction of carbon taxation on average credit risk would be contained: the three different carbon tax levels (EUR 40, EUR 90 and EUR 140 per tonne of CO_2) would increase the average PD by 0.6, 2.3 and 4.1 basis points, respectively. The effect is slightly larger for the Agriculture and Service sectors, while there is no clear pattern relating to firm size.

The strength of our approach lies in its very accurate representation of firm heterogeneity. We directly model energy demand considering the different fuel mix of each firm. We then translate the carbon tax into final energy prices. Using microdata, we can assess what type of firm is more exposed (sector, size, export propensity, position in the income distribution, etc.).

Our approach has some limitations. It is focused on the short term and it is static. We consider only the short-term effect of carbon taxation: there is no translation, no adaptation by the firms and no appraisal of the possible use of the revenues (for example using the proceedings of the carbon tax to reduce other corporate taxes). Our analysis is based on partial equilibrium only: we do not consider the interdependencies between companies and the effects on firms' competitiveness and trade.

On the positive side this approach is rather flexible; it provides a realistic representation of the firms' energy mix and expenditure; it can be used also to assess the impact on credit worthiness of a different type of energy shock, like the one Italian and European firms are experiencing following the disruption in the gas and power markets (see Appendix B).

References

Aiello M.A. and Angelico C. (2022), "The effect of carbon tax on Italian banks' business loan default rates", Journal of Policy Modeling.

Allen T., Dees S., Boissinot J., Caicedo Graciano C., Chouard V., Clerc L., De Gaye A., Devulder A., Diot S., Lisack N., Pegoraro F., Rabaté M., Svartzman R. and Vernet L. (2020), "Climate-Related Scenarios for Financial Stability Assessment: An Application to France", Working Paper Series No. 774, Banque de France.

Balasirishwaron D., Duponcheele G. and Perraudin W. (2022), "ESG and Credit Rating Correlations", Risk Control Research Report 22-16a.

Capasso G., Gianfrate G. and Spinelli M. (2020), "Climate change and credit risk", Journal of Cleaner Production, Volume 266.

de Guindos L. (2021), Keynote speech by Luis de Guindos, Vice-President of the ECB, at the joint ECB and European Commission conference on "European Financial Integration and Stability", Frankfurt am Main, 27 May 2021.

De Socio A., Narizzano S., Orlando T., Parlapiano F., Rodano G., Sette E. and Viggiano G. (2020), "Gli effetti della pandemia sul fabbisogno di liquidità, sul bilancio e sulla rischiosità delle imprese", Note Covid-19, Bank of Italy.

Faiella I. and Mistretta A. (2015), "Spesa energetica e competitività delle imprese italiane", Economia pubblica, v. 42, 3, pp. 85-122.

Faiella I. and Mistretta A. (2022), "The Net Zero Challenge for Firms' Competitiveness", Environ Resource Econ 83, 85–113.

Faiella I. and Malvolti D. (2020), "The Climate Risk for Finance in Italy", Questioni di Economia e Finanza (Occasional Papers) 545, Bank of Italy.

Faiella I. and Lavecchia L. (2021), "Households' energy demand and the effects of carbon pricing in Italy", Questioni di Economia e Finanza (Occasional Papers) 614, Bank of Italy.

Faiella I., Lavecchia L., Mistretta A. and Michelangeli V. (2022), "A climate stress test on the financial vulnerability of Italian households and firms", Journal of Policy Modeling, 44:2, 396-417, March-April.

FSB (2021), "The Availability of Data with Which to Monitor and Assess Climate-Related Risks to Financial Stability".

Giovannelli F., Iannamorelli A., Levy A. and Orlandi M. (2020), "The in-house credit assessment system of Banca d'Italia", Questioni di Economia e Finanza (Occasional Papers) 586, Bank of Italy.

IPCC (2022), "Climate Change 2022: Impacts, Adaptation and Vulnerability", Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Jagers S.C., Martinsson J., Matti S., Povitkina M. (2021), "Why are carbon taxes unfair? Disentangling public perceptions of fairness", Global Environmental Change, Volume 70, 2021, 102356.

Monasterolo I. (2020) “Climate change and the financial system”, Annual Review of Resource Economics 12, pp. 299-320.

NGFS (2018), “NGFS First Progress Report”, October.

NGFS (2022a), “Capturing risk differentials from climate-related risks”.

NGFS (2022b), “Credit ratings and climate change – challenges for central bank operations”.

Vermeulen R., Schets E., Lohuis M., Kolbl B., Jansen D.J. and Heeringa W. (2018), “An energy transition risk stress test for the financial system of the Netherlands”, Occasional studies Volume 16-7, De Nederlandsche Bank (DNB).

Appendix A

Table A.1 - Fiscal year 2019 - Average PD increments by NACE division (basis points)

NACE division	NACE division description	€ 40	€ 90	€ 140	Number of firms
01	Crop and animal production, hunting and related service activities	0.5	1.4	2.7	1,832
02	Forestry and logging	0.1	0.4	0.8	117
03	Fishing and aquaculture	6.3	21.8	39.8	135
10	Manufacture of food products	0.4	1.7	3.4	5,396
11	Manufacture of beverages	0.2	0.9	1.7	715
12	Manufacture of tobacco products	0.3	1.0	1.7	5
13	Manufacture of textiles	0.1	0.5	0.8	2,132
14	Manufacture of wearing apparel	0.3	0.9	1.7	2,387
15	Manufacture of leather and related products	0.2	0.7	1.3	2,205
16	Manufacture of wood and cork; manufacture of articles of straw and plaiting materials	0.2	0.9	1.7	1,896
17	Manufacture of paper and paper products	0.7	3.7	7.9	1,244
18	Printing and reproduction of recorded media	0.2	0.6	1.0	2,025
19	Manufacture of coke and refined petroleum products	14.5	36.5	51.8	81
20	Manufacture of chemicals and chemical products	2.7	12.0	20.1	1,736
21	Manufacture of pharmaceutical products	0.2	0.6	1.2	233
22	Manufacture of rubber and plastic products	0.1	0.5	1.1	3,448
23	Manufacture of other non-metallic mineral products	3.0	13.1	24.3	2,945
24	Manufacture of basic metals	1.5	7.1	13.0	1,023
25	Manufacture of fabricated metal products, except machinery and equipment	0.2	0.7	1.4	14,620
26	Manufacture of computer, electronic and optical products	0.1	0.4	0.7	1,597
27	Manufacture of electrical equipment	0.2	0.7	1.5	2,068
28	Manufacture of machinery and equipment n.e.c.	0.1	0.2	0.4	7,083
29	Manufacture of motor vehicles and trailers	0.1	0.3	0.5	909
30	Manufacture of other transport equipment	0.1	0.4	0.7	732
31	Manufacture of furniture	0.1	0.3	0.6	2,611
32	Other manufacturing	0.1	0.3	0.5	2,015
33	Repair and installation of machinery and equipment	0.1	0.3	0.5	2,766
41	Construction of buildings	0.1	0.4	0.8	11,480
42	Civil engineering	0.1	0.5	0.8	1,984
43	Specialised construction activities	0.1	0.4	0.7	12,392
45	Wholesale and retail trade and repair of motor vehicles and motorcycles	0.2	0.7	1.2	7,515
46	Wholesale trade, except of motor vehicles and motorcycles	0.2	0.7	1.2	28,776
47	Retail trade, except of motor vehicles and motorcycles	0.3	0.9	1.6	16,513

NACE division	NACE division description	€ 40	€ 90	€ 140	Number of firms
49	Land transport and transport via pipelines	5.2	24.1	41.3	7,870
50	Water transport	28.7	68.9	94.4	203
51	Air transport	26.3	59.4	80.9	31
52	Warehousing and support activities for transportation	1.1	3.6	6.9	2,835
53	Postal and courier activities	0.4	1.4	4.3	148
55	Accommodation	0.4	1.7	4.3	5,785
56	Food and beverage service activities	0.8	3.2	7.2	10,241
58	Publishing activities	0.2	0.8	1.4	562
59	Video and television programme production, sound recording and music publishing activities	0.2	0.5	0.9	608
60	Programming and broadcasting activities	0.1	0.4	0.7	144
61	Telecommunications	0.3	1.1	2.3	314
62	Computer programming, consultancy and related activities	0.0	0.1	0.2	3,384
63	Information service activities	0.1	0.1	0.2	2,338
66	Activities auxiliary to financial services and insurance activities	0.1	0.2	0.4	437
68	Real estate activities	0.5	2.6	5.6	1,078
69	Legal and accounting activities	0.2	0.8	1.6	797
70	Activities of head offices; management consultancy activities	0.2	0.6	1.2	1,999
71	Architectural and engineering activities; technical testing and analysis	0.1	0.2	0.3	2,708
72	Scientific research and development	0.4	1.5	2.9	354
73	Advertising and market research	0.1	0.2	0.3	1,288
74	Other professional, scientific and technical activities	0.1	0.3	0.6	1,654
75	Veterinary activities	0.1	0.3	0.4	54
77	Rental and leasing activities	0.1	0.4	0.6	1,268
78	Employment activities	0.0	0.0	0.0	134
79	Travel agency, tour operator and other reservation service and related activities	0.1	0.2	0.4	1,068
80	Security and investigation activities	0.4	1.1	2.3	361
81	Services to buildings and landscape activities	0.3	0.8	1.4	2,293
82	Office administrative, office support and other business support activities	0.1	0.2	0.4	1,707
85	Education	0.1	0.3	0.5	1,136
86	Human health activities	0.2	0.6	1.1	3,334
87	Residential care activities	0.5	1.9	3.9	1,062
88	Social work activities without accommodation	0.7	2.6	4.9	1,291
90	Creative, arts and entertainment activities	0.7	3.1	6.0	423
91	Libraries, archives, museums and other cultural activities	1.1	4.8	7.9	77
92	Gambling and betting activities	0.3	0.8	1.4	206
93	Sports activities and amusement and recreation activities	1.0	5.1	11.1	1,902

NACE division	NACE division description	€ 40	€ 90	€ 140	Number of firms
95	Repair of computers and personal and household goods	0.4	1.2	2.4	354
96	Other personal service activities	0.7	5.4	10.7	1,813

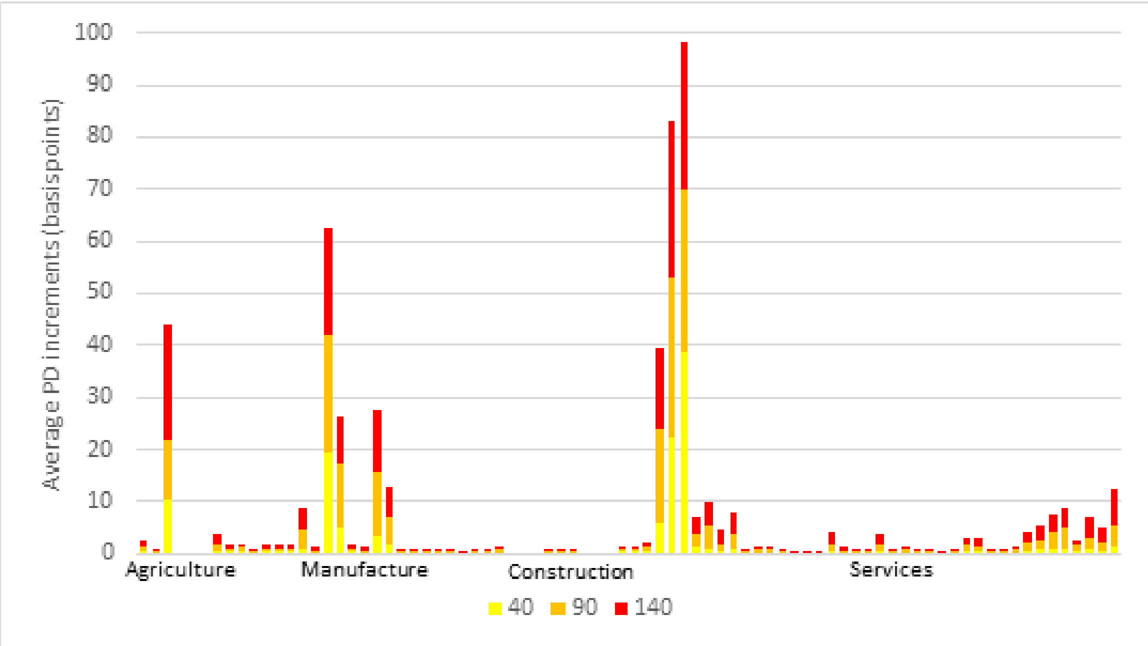
Table A.2 - Fiscal year 2018 - Average PD increments by sector (basis points)

Sector	Carbon tax			Number of firms
	€ 40	*€ 90*	*€ 140*	
Agriculture	1.1	2.6	5.0	1,971
Construction	0.1	0.4	0.7	22,630
Manufacturing	0.6	2.2	3.8	58,680
Services	0.8	3.0	5.4	101,043
Entire sample	0.7	2.4	4.3	184,324

Table A.3 - Fiscal year 2018 - Average PD increments by dimensional class (basis points)

Size	Carbon tax			Number of firms
	€ 40	*€ 90*	*€ 140*	
Micro	0.7	2.4	4.3	101,071
Small	0.7	2.5	4.4	62,830
Medium	0.7	2.4	4.1	16,308
Large	0.5	1.5	2.6	4,115
Entire sample	0.7	2.4	4.3	184,324

Figure A.1 - Fiscal year 2018 - Average PD increments by NACE division (basis points)



Appendix B

In the period from mid 2021 to the end of 2022, COVID-related disruptions to the global supply chain and the Russian invasion of Ukraine have pushed energy prices to record levels. This shock in energy costs constitutes a significant risk for Italian firms, thus increasing their vulnerability. We use our approach to translate these higher costs into a notional carbon tax of EUR 420 and assess its impact on the PDs in order to give a preliminary insight on the potential effects of these energy cost spikes. This preliminary analysis will be updated when more recent financial data will become available, together with information on the evolution of energy prices and demand.

Considering the Italian economy, the short-term effect on the average PD of a EUR 420 carbon tax would be relevant but still moderate, involving an increase by 13.4 basis points.

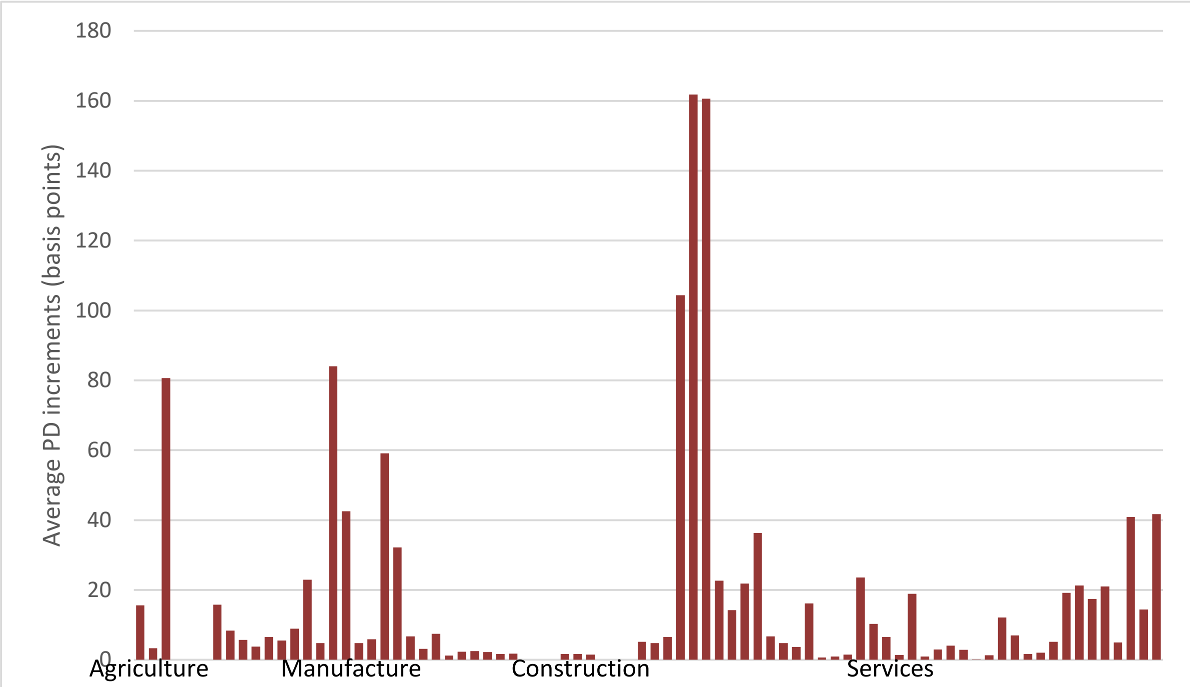
Table B1 - Average PD increments by sector (basis points)

Sector	Carbon tax *€ 420*	Number of firms
Agriculture	19.1	2,084
Construction	1.6	25,856
Manufacturing	10.3	61,872
Services	17.7	116,065
Entire sample	13.4	205,877

An analysis at NACE 2-digit division level confirms the high heterogeneity of the effects on average PDs (Figure B1). The most exposed industries are the same reported in Figure 2, with the three Transport sub-sectors (Water, Air and Land) showing the highest effect on PDs. For these sectors, the rise in the energy prices due to a EUR 420 carbon tax would raise the average PD in the range between 80.7 (Fishing) and 161.8 basis points (Water transport).

Comparing the results reported in Figure B1 with the ones in Figure 1, we notice that the spike in the energy cost causes a relevant effect on the credit worthiness of a larger number of sectors. With a EUR 140 carbon tax only five sectors show an average PD increase above 30 basis points. In the stress scenario also other manufacturing sectors (such as the manufacture of chemical products, non-metallic mineral products and basic metals) and services sectors (food and beverage, sports and recreation activities, and other personal services) would be affected by more than 30 basis points on average. Consequently, the increase in production costs due to the increase in electricity and gas prices experienced in Italy during 2022 has been a major risk source for several economic sectors. The targeted measures adopted by the Italian Government for energy-intensive firms have clearly helped mitigate the burden of the price shock.

Figure B1 - Average PD increments by sector (basis points)



Papers published in the 'Markets, Infrastructures, Payment Systems' series

n. 1 TIPS - TARGET Instant Payment Settlement – The Pan-European Infrastructure for the Settlement of Instant Paymentsi, *by Massimiliano Renzetti, Serena Bernardini, Giuseppe Marino, Luca Mibelli, Laura Ricciardi and Giovanni M. Sabelli* (Institutional Issues)

n. 2 Real-Time Gross Settlement systems: breaking the wall of scalability and high availability, *by Mauro Arcese, Domenico Di Giulio and Vitangelo Lasorella* (Research Papers)

n. 3 Green Bonds: the Sovereign Issuers' Perspective, *by Raffaele Doronzo, Vittorio Siracusa and Stefano Antonelli* (Research Papers)

n. 4 T2S - TARGET2-Securities – The pan-European platform for the settlement of securities in central bank money, *by Cristina Mastropasqua, Alessandro Intonti, Michael Jennings, Clara Mandolini, Massimo Maniero, Stefano Vespucci and Diego Toma* (Institutional Issues)

n. 5 The carbon footprint of the Target Instant Payment Settlement (TIPS) system: a comparative analysis with Bitcoin and other infrastructures, *by Pietro Tiberi* (Research Papers)

n. 6 Proposal for a common categorisation of IT incidents, *by Autorité de Contrôle Prudentiel et de Résolution, Banca d'Italia, Commissione Nazionale per le Società e la Borsa, Deutsche Bundesbank, European Central Bank, Federal Reserve Board, Financial Conduct Authority, Ministero dell'Economia e delle Finanze, Prudential Regulation Authority, U.S. Treasury* (Institutional Issues)

n. 7 Inside the black box: tools for understanding cash circulation, *by Luca Baldo, Elisa Bonifacio, Marco Brandi, Michelina Lo Russo, Gianluca Maddaloni, Andrea Nobili, Giorgia Rocco, Gabriele Sene and Massimo Valentini* (Research Papers)

n. 8 The impact of the pandemic on the use of payment instruments in Italy, *by Guerino Ardizzi, Alessandro Gambini, Andrea Nobili, Emanuele Pimpini and Giorgia Rocco* (Research Papers) (in Italian)

n. 9 TARGET2 – The European system for large-value payments settlement, *by Paolo Bramini, Matteo Coletti, Francesco Di Stasio, Pierfrancesco Molina, Vittorio Schina and Massimo Valentini* (Institutional Issues) (in Italian)

n. 10 A digital euro: a contribution to the discussion on technical design choices, *by Emanuele Urbinati, Alessia Belsito, Daniele Cani, Angela Caporrini, Marco Capotosto, Simone Folino, Giuseppe Galano, Giancarlo Goretti, Gabriele Marcelli, Pietro Tiberi and Alessia Vita* (Institutional Issues)

n. 11 From SMP to PEPP: a further look at the risk endogeneity of the Central Bank, *by Marco Fruzzetti, Giulio Gariano, Gerardo Palazzo and Antonio Scalia* (Research Papers)

n. 12 TLTROs and collateral availability in Italy, *by Annino Agnes, Paola Antilici and Gianluca Mosconi* (Research Papers) (in Italian)

n. 13 Overview of central banks' in-house credit assessment systems in the euro area, *by* Laura *Auria, Markus Bingmer, Carlos Mateo Caicedo Graciano, Clémence Charavel, Sergio Gavilá, Alessandra Iannamorelli, Aviram Levy, Alfredo Maldonado, Florian Resch, Anna Maria Rossi and Stephan Sauer* (Institutional Issues)

n. 14 The strategic allocation and sustainability of central banks' investment, *by Davide Di Zio, Marco Fanari, Simone Letta, Tommaso Perez and Giovanni Secondin* (Research Papers) (in Italian)

n. 15 Climate and environmental risks: measuring the exposure of investments, *by Ivan Faiella, Enrico Bernardini, Johnny Di Giampaolo, Marco Fruzzetti, Simone Letta, Raffaele Loffredo and Davide Nasti* (Research Papers)

n. 16 Cross-Currency Settlement of Instant Payments in a Multi-Currency Clearing and Settlement Mechanism, *by Massimiliano Renzetti, Fabrizio Dinacci and Ann Börestam* (Research Papers)

n. 17 What's ahead for euro money market benchmarks?, *by Daniela Della Gatta* (Institutional Issues) (in Italian)

n. 18 Cyber resilience per la continuità di servizio del sistema finanziario, *by Boris Giannetto and Antonino Fazio* (Institutional Issues) (in Italian)

n. 19 Cross-Currency Settlement of Instant Payments in a Cross-Platform Context: a Proof of Concept, *by Massimiliano Renzetti, Andrea Dimartina, Riccardo Mancini, Giovanni Sabelli, Francesco Di Stasio, Carlo Palmers, Faisal Alhijawi, Erol Kaya, Christophe Piccarelle, Stuart Butler, Jwallant Vasani, Giancarlo Esposito, Alberto Tiberino and Manfredi Caracausi* (Research Papers)

n. 20 Flash crashes on sovereign bond markets – EU evidence, *by Antoine Bouveret, Martin Haferkorn, Gaetano Marseglia and Onofrio Panzarino* (Research Papers)

n. 21 Report on the payment attitudes of consumers in Italy: results from ECB surveys, *by Gabriele Coletti, Alberto Di Iorio, Emanuele Pimpini and Giorgia Rocco* (Institutional Issues)

n. 22 When financial innovation and sustainable finance meet: Sustainability-Linked Bonds, *by Paola Antilici, Gianluca Mosconi and Luigi Russo* (Institutional Issues) (in Italian)

n. 23 Business models and pricing strategies in the market for ATM withdrawals, *by Guerino Ardizzi and Massimiliano Cologgi* (Research Papers)

n. 24 Press news and social media in credit risk assessment: the experience of Banca d'Italia's In-house Credit Assessment System, *by Giulio Gariano and Gianluca Viggiano* (Research Papers)

n. 25 The bonfire of banknotes, *by Michele Manna* (Research Papers)

n. 26 Integrating DLTs with market infrastructures: analysis and proof-of-concept for secure DvP between TIPS and DLT platforms, *by Rosario La Rocca, Riccardo Mancini, Marco Benedetti, Matteo Caruso, Stefano Cossu, Giuseppe Galano, Simone Mancini, Gabriele Marcelli, Piero Martella, Matteo Nardelli and Ciro Oliviero* (Research Papers)

n. 27 Statistical and forecasting use of electronic payment transactions: collaboration between Bank of Italy and Istat, *by* Guerino Ardizzi and Alessandra Righi (Institutional Issues) (in Italian)

n. 28 TIPS: a zero-downtime platform powered *by* automation, by *Gianluca Caricato, Marco Capotosto, Silvio Orsini and Pietro Tiberi* (Research Papers)

n. 29 TARGET2 analytical tools for regulatory compliance, *by Marc Glowka, Alexander Müller, Livia Polo Friz, Sara Testi, Massimo Valentini and Stefano Vespucci* (Institutional Issues)

n. 30 The security of retail payment instruments: evidence from supervisory data, *by Massimiliano Cologgi* (Research Papers)

n. 31 Open Banking in the payment system: infrastructural evolution, innovation and security, supervisory and oversight practices, *by Roberto Pellitteri, Ravenio Parrini, Carlo Cafarotti and Benedetto Andrea De Vendictis* (Institutional Issues) (in Italian)

n. 32 Banks' liquidity transformation rate: determinants and impact on lending, *by Raffaele Lenzi, Stefano Nobili, Filippo Perazzoli and Rosario Romeo* (Research Papers)

n. 33 Investor behavior under market stress: evidence from the Italian sovereign bond market, *by Onofrio Panzarino* (Research Papers)

n. 34 Siamese neural networks for detecting banknote printing defects, *by Katia Boria, Andrea Luciani, Sabina Marchetti and Marco Viticoli* (Research Papers) (in Italian)

n. 35 Quantum safe payment systems, *by Elena Bucciol and Pietro Tiberi*

n. 36 Investigating the determinants of corporate bond credit spreads in the euro area, *by Simone Letta and Pasquale Mirante*

n. 37 Smart Derivative Contracts in DatalogMTL, *by Andrea Colombo, Luigi Bellomarini, Stefano Ceri and Eleonora Laurenza*

n. 38 Making it through the (crypto) winter: facts, figures and policy issues, *by Guerino Ardizzi, Marco Bevilacqua, Emanuela Cerrato and Alberto Di Iorio*

n. 39 The Emissions Trading System of the European Union (EU ETS) *by Mauro Bufano, Fabio Capasso, Johnny Di Giampaolo and Nicola Pellegrini* (in Italian)

n. 40 Banknote migration and the estimation of circulation in euro area countries: the italian case *by Claudio Doria, Gianluca Maddaloni, Giuseppina Marocchi, Ferdinando Sasso, Luca Serrai and Simonetta Zappa* (in Italian)