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A MICRO-FOUNDED CLIMATE STRESS TEST ON THE FINANCIAL VULNERABILITY OF ITALIAN HOUSEHOLDS AND FIRMS

by Ivan Faiella, Luciano Lavecchia, Valentina Michelangeli and Alessandro Mistretta*

Abstract

This study presents a novel methodological framework for assessing the exposure of the Italian financial system to climate policy risks, using a micro-founded approach. By combining survey and administrative data with energy accounts and energy prices, we estimate the energy demand elasticity of Italian households and firms at the micro-level and we use this information to simulate the effects of four one-off carbon taxes (corresponding to €50, €100, €200 and €800 per ton of CO2) on their income and profits. To compute if (and how) carbon taxes might affect the share of financially vulnerable agents and the debt at risk, these estimates are used as an input for the microsimulation models used to monitor financial stability at the Bank of Italy. According to our results, a level of carbon taxation within the range of €50-200 per ton does not have a sizeable effect on the share of financially vulnerable agents. The micro approach allows us to take into account the heterogeneous transmission channels of climate risks and indicates that the financial risks stemming from climate shocks are limited overall and specific to individual households and industries.

JEL Classification: Q41, Q54, Q58.
Keywords: climate change, carbon tax, climate stress test, financial vulnerability.
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Contents

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1 Introduction*

The effects of climate change constitute a possible threat to economic activity and the stability of the financial system. In addition, the policies to support the transition will have an impact on the economy and on financial institutions'.[1] Several governments have set ambitious climate targets, with nine of the ten biggest economies committed to net-zero goals (among them the UK, the EU, the United States and Japan, which have pledged to reach net carbon neutrality by 2050, while China has set up a similar goal for 2060). This translates into an unprecedented change in the way countries transform and use energy. The EU has been at the forefront of the climate debate and at the end of 2019, it pledged to cut greenhouse gas (GHG) emissions by 55 per cent by 2030 with 1990 as the base year.

Quantifying climate-related financial risks is however a challenging task. Indeed, at least in recent history, there have been no climate or environmental patterns whose implications are comparable with those for the future, which are then marked by high uncertainty, knock-on effects (endogeneity) and non-linearities (IPCC, 2014). Moreover, an evaluation at the individual intermediary level is a complex process, made even more difficult by the lack of detailed data on the exact geographical location, the economics or the carbon content of individual activities and assets (ECB, 2020). Finally, aggregating the estimated risks to assess the implications for the financial system as a whole requires making assumptions on how these risks propagate among intermediaries and on any amplification mechanisms - between connected sectors or countries and also including feedbacks from the financial system to the real economy - or on the effects of risk mitigants (such as insurance or other hedging strategies).

The academic world has been extensively investigating how climate change can affect the macro economy (see Batten et al. 2016, McKibbin et al. 2017, Campiglio et al. 2018, Campiglio and van der Ploeg 2021) and how financial regulators should consider climate risks (among others, see Dikau and Volz 2018, Schoenmaker 2019, Bolton et al. 2020 and Robins et al. 2021). In general, analyses of the impact of climate change over a medium- and long-term horizon can help central banks and supervisory authorities in understanding the possible implications for financial stability, but require making assumptions on the evolution of the markets farther into the future.

In this work, we present an alternative to the standard macro-based climate stress tests, by assessing the exposure of the Italian financial system to climate policy risks using a micro-founded approach. Our approach allows us to account for heterogeneity and, consequently, for the differential exposure of households and firms to a climate shock, which is identified as the introduction of a one-off carbon tax. Despite being one of the EU countries with the highest level of energy taxation, Italy has not explicitly introduced such a tax and, given its commitment to significantly reducing GHG emissions in the coming years

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[1] 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

within the EU Green Deal for Europe, it is a very suitable policy option on which to apply our stress test exercise. Specifically, we consider four possible carbon taxes, ranging from the current price level on the EU-ETS (€50) to an extreme one (€800), which corresponds to the value of the social cost of carbon (SCC, more on this later) in the event of a "Disorderly transition"; here, the transition is postponed, there are only a couple of decades left to achieve net-zero and this requires a strong price signal (NGFS 2021). According to our results, the overall effect of carbon taxation on financial vulnerability is limited and mostly concentrated on firms. All in all, the exercise suggests that a climate shock would raise the vulnerability of both households and firms, but, even in the extreme case (€800), it would remain below the peak reached during the sovereign debt crisis. With this paper, we contribute to both the strand of the literature on micro-founded analyses of households and firms' energy demand, including its reaction to price changes, and to the literature on the effect of carbon pricing on financial vulnerability.

More in detail, we start by estimating the energy demand (in energy units) and derive price elasticities for Italian households and firms, exploiting microeconomic data. For households, we follow the methodology of Faiella and Lavecchia (2021), which uses the pseudo panel of the Italian Household Budget Survey (HBS)[2] to estimate short- and long-run price elasticities for three different energy services (electricity, heating and private transport fuels). For firms, we exploit firm-level administrative data (from the Cerved database), integrated with Eurostat industry-level data on firms' energy use, to estimate how energy demand changes as prices change. For both households and firms, the elasticities are estimated for different groups, exploiting most of the granular information available.

We then compute the energy price variations of each energy fuel corresponding to the carbon tax considered (using the carbon emissions factors for each fuel). These variations are then translated into a policy shock using the estimated price elasticities. Each group of households and firms reacts according to its own energy mix and price sensitivities. This in turn changes the amount and the mix of energy demanded and affects their energy expenditure correspondingly. The change in energy expenditure then has an impact on the resources available after the introduction of the carbon tax: for households via a reduction in disposable income, for firms through a change in their EBITDA.

We finally feed the estimated changes in the available resources into the definitions and the set of models developed by the Bank of Italy to monitor financial vulnerability (Michelangeli and Pietrunti (2014a) and Attinà et al. (2020) for households and De Socio and Michelangeli (2017) for firms. The mechanism is the following: by reducing disposable income for households and EBITDA for firms, a carbon tax could lead to an increase in financial vulnerability as the resources available to service the debt decrease. We compute the change in financial vulnerability driven by the carbon tax using the last year for which data are available as a benchmark (i.e. 2016 for households and 2018 for firms).

[2] "Indagine sulla spesa delle famiglie", Istat.

Here the main results for households and firms.
Households - Without carbon taxation, the shares of vulnerable households and of their debt (i.e. debt at risk) are equal to 1.6 and 10.3 per cent respectively in the benchmark year. Introducing a carbon tax of moderate size (€50) implies an increase of 6 and 50 basis points respectively in the two variables. The highest carbon tax (€800) would raise the two indicators to 1.8 and 12.2 per cent, far below the peak reached during the sovereign debt crisis, when the shares of vulnerable households and of their debt were equal to 2.8 and 19.4 per cent. The households most exposed to the carbon tax are those with a younger reference person (aged 16-39), while the "older" and larger ones are less affected.

Firms - In the baseline scenario, the shares of vulnerable firms and of their debt equal 22.4 and 27.4 per cent respectively in the benchmark year. A carbon tax of €50 would raise the two indicators to 32.5 and 30.3 per cent. The impact of the shock is quite heterogeneous. In the baseline, the most vulnerable sectors in terms of debt at risk are construction and energy, whose vulnerabilities increase marginally after the introduction of a €50 carbon tax (by 3.6 and 0.8 percentage points). This tax would have a larger impact on the manufacturing sector, raising the debt at risk by about 5 percentage points, to 26.4 per cent. With respect to the size, micro firms are the most vulnerable ones in terms of debt at risk and are the most exposed to our climate shock. Introducing an €800 carbon tax would raise the debt at risk of micro firms to 54 per cent, a high level but still below the peak reached during the sovereign debt crisis (over 55 per cent).

In our exercise, we only consider the instantaneous impact on households' and firms' vulnerability of a one-off introduction of a carbon tax. We abstract from a long-run assessment of the risks, as over time many forces can come into play to mitigate the effects (such as shifting to other activities or technologies) and the results may be subject to a higher level of uncertainty. This is a serious limitation of the analysis, but it reduces the amount of hypothesis needed and makes the transmission channels for climate shocks clearer. For this reason, we plan to complement this analysis with a fully-fledged top-down exercise, where a more long-term perspective will be adopted and some adaption mechanisms will also drive the results.

The structure of the paper is the following. Section 2 presents an overview of the stress tests carried out so far by central banks to assess climate risks; Section 2 explains our choice to use an introduction of a carbon tax as a climate shock; Section 4 describes our data and methodologies for simulating the climate shock. Section 5 shows the set of models used to assess how the climate shock affects households' and firms' financial vulnerability; detailed results of the exercise are presented in Section 6. Section 7 draws the main conclusions and sets the future research agenda.

2 Climate stress tests and central banks

Assessing the threat posed by climate change on the financial system is critical. However, this assessment is complicated by specific aspects, such as the profound uncertainty surrounding the effects of climate change, their longer timescale compared with the horizon of financial markets, the transmission channels to the economy, and the influence of mitigation and adaptation policies (Monasterolo, 2020).

Central banks may include climate risk management in their activities in many ways (Bernardini et al., 2021), starting with projects to raise awareness on these issues, for example by drafting guidelines or through other initiatives involving bankers, investors and other stakeholders (including savers). Moreover, a central bank can help the financial market to deal with these issues by establishing information requirements or by encouraging the issuance and trading of climate-friendly securities (such as climate and green bonds). As a supervisory authority, it can also set it expectations regarding the management and disclosure of climate risks of financial intermediaries. For example, the Single Supervisory Mechanism (SSM) has published a list of its non-binding expectations for directly supervised banking groups (Single Supervisory Mechanism, 2020).

Some central banks have indeed been integrating climate scenarios and risks into pre-existing stress test templates. A key step in the process of designing such an exercise is the definition of a set of climate scenarios. To date, the authorities have followed two main approaches. The first, adopted by the French Autorité de contrôle prudentiel et de résolution (ACPR; Allen et al. 2020), employs scenarios based on the Integrated Assessment Models (IAM) that are already available. The second, instead, uses ad hoc scenarios, such as those in the stress test conducted by De Nederlandsche Bank (DNB; Vermeulen et al. 2018, 2019). Both methods utilize several alternative scenarios that reflect different assumptions regarding, for example, the policies deployed to mitigate climate change. More recently, the Network for Greening the Financial System (NGFS)[3] has produced a set of standard climate scenarios (NGFS 2020 and NGFS 2021), to help central banks and supervisory authorities to refer to a common set of information that is homogeneous and comparable.

The climate stress tests conducted so far include both top-down models looking at the short-to-medium term (up to five years) and using data that are aggregated at sectoral level and bottom-up models considering a longer time horizon (up to 30 years) and employing granular data. For example, in 2017, the DNB completed a test[4] on the Dutch financial system (Vermeulen et al., 2019).

[3]The Network for Greening the Financial System (NGFS) is a global network created in 2017 and made up of 90 among 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.

[4]The DNB climate stress test covered €2.3 trillion of equities, bonds and loans from 80 Dutch financial institutions (banks, insurances and pension funds). The DNB built four disruptive scenarios by interacting climate policies and energy technology innovations, i.e. focusing on transition risk. They find that financial losses can add up to 11 per cent of portfolio

Banque de France and its supervisory arm, the ACPR, developed an analytical framework (Allen et al., 2020) to assess the risks stemming from climate policy[5] while the of England (2019)[6] and the ECB[7] are conducting exercises that will be completed in 2022-2023.

This paper takes a different perspective and it is part of a broader effort within the Bank of Italy to monitor the sensitivity of the financial system to growing stringency of climate policies (then only focusing on transition risks). To our knowledge, this is the first micro-founded exercise that tries to shed light on the effects of climate policies, accounting for the heterogeneous exposure to climate risks of different types of households and firms.

3 Why focusing on carbon taxation

We model the climate shock as a one-off carbon tax on final energy uses. A carbon tax is one of the most likely climate policy shocks, due to its effectiveness. However, the mechanism, i.e. a change in the relative price among energy alternatives, might arise from other types of transition risks, such as a ban on a specific type of carbon-intensive technology (e.g. burning coal for producing electricity or driving internal combustion engines' cars), or the subsidization of low-carbon sources (renewables) or technologies (Energy Efficiency, Carbon Capture and Storage). Although it is not the only policy tool available, carbon pricing is considered the most efficient measure to reduce GHG emissions (Tirole, 2017). It is also a pillar of the EU Green Deal to achieve climate neutrality in the EU by mid-century.[8] Indeed, carbon pricing mitigates the mis-

values or between €49 and €159 billion, and identify the so-called "transition vulnerability factors", which measure transition risks at the industry-level.

[5]The ACPR climate stress test involved a representative group of banks and insurance companies (around 80 per cent of total assets) in a bottom-up approach. Results were published in May 2021. The ACPR climate stress test considered three transition risk scenarios and one physical risk scenario, up to 2030, covering banking groups and insurers. The exercise varied across different levels of carbon taxes and productivity. In no case, an economic downturn by 2050 was found. The Banque de France plans to carry on this exercise regularly in the future.

[6]The Bank of England launched at the end of 2019 a proposal to explore the financial risks posed by climate change within its 2021 biennial exploratory scenario (BES). First stopped due to the COVID-19 crisis, the BES was restarted in November 2020 and should be completed by May 2022 (reference year: 2020). The exercise will involve the largest British banks and insurance companies. These, in turn, will have to estimate the exposure and the losses induced by physical and transition risks on a 30-year modelling horizon (from 2020 to 2050) based on the second set of scenarios provided by the NGFS (2021)

[7]Currently, there is a discussion within the SSM on the design of a climate stress test involving the major European banks, which will build on the inputs provided by another exercise carried on by the ECB. The latter is evaluating the effects of physical risk on more than 2.000 European banks and 4 million companies in the next 30 years (results to be published by 2022 and its results will feed into the SSM exercise. See, *Shining a light on climate risks: the ECB's economy-wide climate stress test*, blog post by Luis de Guindos, Vice-President of the ECB, 18 March 2021.

[8]The European Green Deal requires to achieve climate neutrality by 2050 and expands the perimeter of carbon pricing, extending the coverage of the EU-ETS, introducing a carbon tax on non-ETS sectors and levying a Carbon Border Adjustment on imported goods of carbon-

pricing of climate risks and provides an incentive for firms to move away from fossil-fuel technologies and adopt (or develop) carbon-free technologies, fostering innovations (Nordhaus, 2021). Moreover, by increasing the relative prices of fossil-related products, a carbon tax not only promotes the switching to lower-carbon fuels but also encourage energy conservation. The empirical assessment of carbon pricing is not conclusive: some empirical analyses find very small or nil negative effects on economic activity and job creation (Metcalf and Stock 2020); a recent meta-analysis points to a significant negative firms' competitive and distributional impact of carbon pricing (Penasco et al., 2021). A recent paper assesses the effect of a set of one-off carbon taxes on the energy demand of Italian households and finds that in all simulations the price increase triggered by the carbon tax is regressive: poorer households expenditure increases more while they also suffer a greater drop in their energy use (Faiella and Lavecchia 2021).

Another practical issue is the identification of what is the right price to achieve the climate targets. In a Pigouvian setup, a carbon tax should be equal to the marginal damage of emitting an additional ton of carbon dioxide, i.e. the social cost of carbon (SCC). However, there are literally thousands of estimates of the SCC (almost 6,000 as of April 2021 according to Tol 2021), with a huge variability that depends on the hypotheses and the methodologies adopted (Hernandez-Cortes and Meng, 2020; Pindyck, 2013, 2017). According to the IMF (2019), in order to achieve the Paris Agreement targets, a carbon tax should be introduced and rise quickly to $75 (about €66) per ton of CO2 by 2030. Similarly, the IEA (2020) estimates a carbon tax of $63 per ton of CO2 in 2025 increasing to $140 in 2040 under its Sustainable Development scenario. Other simulations point to higher carbon prices ranging from $20 to $360 in 2030 and from $85 to $1,000 in 2050, depending on the stringency of the target, the smoothness of the transition and the availability of carbon removal technologies (Guivarcha and Rogeljb, 2017).

Germany has recently introduced a carbon tax covering emissions outside the perimeter of the EU-ETS system (following other EU countries like France and Denmark, see Batini et al. 2020)), that in May 2021 was pricing emissions around €50 per ton of CO2. Germany has recently introduced a carbon tax covering emissions outside the perimeter of the EU-ETS system (following other EU countries like France and , that in May 2021 was pricing emissions around €50 per ton of CO2.

Italy has not such a tax yet and, given its commitment to significantly reduce GHG emissions in the coming years, it is then very suitable to study the impact of its likely introduction.

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intensive sectors.

4 Data, estimation and simulation of the carbon tax

4.1 Households

Faiella and Lavecchia (2021) estimate the short- and long-run price elasticity of energy demand for each energy service (electricity, heating and private transport fuels) using the sample-survey monthly information from the HBS, carried out each year by Istat (the National Statistical Office) integrated with other sources of information (on energy prices and energy use). As the HBS is not a panel, the authors, following Faiella and Cingano (2015), use a *quasi*-panel approach (Deaton, 1985), which compares the values of population subgroups, classified in *strata*[9], and estimate the demand elasticity for each group exploiting the change in time of energy prices and demand. Using this data, they fit the following autoregressive distributed lag (ARDL) model (Greene, 2008):

$$logQ^z_{s,t} = \lambda_s logQ^z_{s,t-1} + \beta_s logP^z_t + \gamma_s logE_{s,t} + w + s + t + t^2 + \epsilon_{s,t} \quad (1)$$

where $Q^z_{s,t}$ is the fuel z consumed by stratum s in the month t, P^z_t is the average price of fuel z, w and s are seasonal dummies, $E_{s,t}$ is the total expenditure of stratum and β_s is the coefficient of interest, the (short-run) price elasticity. The results, summarized in table 1, show that households' price elasticity is 1) greater in the long-run; 2) in the short-run is smaller and similar across energy services. The least square estimates suggest that demands for heating and electricity are more responsive to price changes: a 1 per cent rise in prices reduces the energy demanded by 0.36 (0.40) per cent for electricity (heating) in the short-run. The least square estimate for liquid fuels, instead, implies a lower effect: a 1 per cent rise in petrol or gasoil prices reduces demand by 0.17 per cent in the short-run. The two-stage least square (2SLS) estimates confirm the impact of price changes on energy demand. In our setting, we will build on the least square price estimates available at *stratum* level, which will feed into a model of households' financial vulnerability in Section 5.2.

Strata-level estimates show that less affluent households are more reactive to price increases for electricity, while for heating the demand responsiveness seems more uniform across the expenditure distribution. For transport fuels, less affluent households again react more, but estimated parameters are less accurate.

4.2 Firms

Energy expenditure is increasingly relevant to assess the effects of climate and energy policies on firms' competitiveness (Ward et al., 2019). According to

[9] The authors identify nine subgroups of households observed across the fourth of equivalent expenditure distribution. In total, there is information on 36 subgroups observed each month between 1997 and 2018.

Faiella and Mistretta (2015), the purchase of energy products in the Italian manufacturing sector (amounting on average to about 2.4 per cent of total sales) plays a relevant role in strategic business decisions, such as the ability to sell their products on foreign markets. According to a recent study, in the last years unit energy costs have been increasing, reaching about one-third of unit labour costs, and this is associated with a contraction in bilateral exports (Faiella and Mistretta, 2020). The pressure of energy purchases on firms' competitiveness is a strategic issue also in the EU (European Commission, 2014), in particular, if one considers the future costs of going climate neutral by mid-century.

To derive the amount of energy expenditure for firms, we start exploiting firms' balance sheets from the Company Accounts Data System (Cerved-Centrale dei Bilanci). This yearly database covers all the Italian non-financial limited liability companies. For each firm, we extract information on industry, value-added, revenues, cost of labour, expenditure on intermediate goods and services, but firm level data on energy consumption is not available. The Cerved-Centrale dei Bilanci dataset is then matched, at the firm level, with the employment data from the National Institute of Social Security (INPS), which contains information on employment the firm level. Using the (macro) official statistics on energy demand we compute energy demand per employee at the industry level; then we impute firm level data on energy consumption exploiting the number of employees at firm level (for more details, see Appendix B.1). Our final dataset thus contains, for each firm, data also on energy consumption.

For each firm i in our database, we, therefore, can estimate the energy demand of the $z-th$ fuel in the year t, $e_{i,z,t}$. To move from energy demand to energy expenditure, we use for electricity and natural gas the Eurostat bi-annual prices for non-domestic users and for oil products monthly prices provided by the Italian Ministry of the Economic Development (MISE), $P_{z,t}$. We then compute the energy costs at the firm level for each fuel, $c_{i,z,t}$, as follows:

$$c_{i,z,t} = e_{i,z,t} * P_{z,t}. \tag{2}$$

To analyse companies' energy demand and compute their price elasticity, we estimate the overall elasticity of fossil sources to the relative average price (see, among others Smith et al., 1995). In particular, using a common *numeraire* to express the energy content of all fossil sources,[10] it is possible to obtain the total fossil fuel consumed by each firm, $F_{i,t}$:

$$F_{i,t} = \sum_z e_{i,z,t}. \tag{3}$$

We then compute an average price at the company level:

$$P_{i,t} = \frac{\sum_z e_{i,z,t} * P_{z,t}}{F_{i,t}}. \tag{4}$$

[10] Such as tons of oil equivalent (TOE) or terajoule (TJ).

Finally, to obtain price elasticity, using data covering the 2008-2018 period, as already done for households, we estimate the following log-log specification:

$$log(F_{i,t}) = \lambda log(F_{i,t-1}) + \beta log(P_{i,t}) + t + t^2 + X_{i,t} + \mu_i + \epsilon_{i,t} \tag{5}$$

In equation 5, firms' fossil fuel demand depends on the current price and on a set of additional controls, such as information about firms' energy efficiency, market power, value-added and share of renewable sources in the energy mix; additionally, we control for a time quadratic trend. We estimate this equation using OLS[11] for the whole sample and for different sub-samples (obtained grouping firms in eight strata according to their NACE sector and size).

According to these estimates reported in table 2, energy demand reacts to changes in energy prices. On average, a 1 per cent increase in energy prices reduces firms demand by about 0.23 percentage points, but we also find a certain degree of heterogeneity. Construction firms are the most sensitive to price changes (decreasing their demand by about 0.6 percentage points); on the contrary, fossil fuel demand in agriculture seems to be inelastic. Services are less reactive than industry, in particular for firms with more than 50 employees operating in services.

5 Simulation of financial vulnerability

5.1 Setup of the simulation

In this Section, we present the assumptions behind our exercise aimed at assessing the impact of a climate policy shock on households' and firms' vulnerability. Vulnerability from a financial stability point of view does not necessarily mean default, but it refers to a possible difficulty in meeting debt payments when a negative shock hits them. Many vulnerable households and firms are solvable if economic conditions do not change, but, if a negative shock occurs, they can move from a condition of vulnerability to one of default. We thus aim at identifying indebted agents that could potentially be problematic both for themselves (as, for instance, they could lose their house) and for the liquidity and solvability of financial intermediaries.

We simulate the effects of four carbon taxes expressed in real € for 2015: €50, €100, €200 and €800 per ton of CO2. In practice, carbon taxes are set in a specific year and then progressively increased according to predetermined steps. However, in our setting, we assume a one-off introduction on final energy use on top of existing taxes on energy (and costs levied as part of the EU-ETS).

The choice of these values for a carbon tax are guided by the following considerations: a carbon tax of €50 is close to the current price on the EU-ETS

[11] Because we observe price and quantity at equilibrium, there might be an issue of endogeneity (price can be influenced both by supply and demand changes). Therefore, we also employ an IV estimator using wholesale prices as instruments, assuming that firms' demand marginally influences them. This is obvious for international oil markets, and it does not seem unreasonable for domestic electricity and gas markets. Results are broadly the same as those obtained using OLS.

market and to the value of the French carbon tax (in 2020 €56) and it is almost the double of the recently introduced German tax scheme (€25). However, this value is not consistent with the Paris targets: the IMF (2019) suggests a global carbon tax of €66 ($ 75) by 2030 to meet the 2°C target, while The Carbon Pricing Leadership Coalition (2017) suggests introducing a carbon price level ranging between €35 and €70 ($ 40-80) per ton of CO2 by 2020. Some studies argue that a carbon tax of €200 is required to meet the long-term EU targets[12] while McKinsey (2020) forecasts a carbon tax of €100 would not be sufficient to make all the required investments profitable. As for €200 and €800 we refer to the peak values of the SCC estimates in two of the scenarios prepared by NGFS (NGFS 2020, 2021), i.e. corresponding to the values of the SCC under an "Orderly transition" and a "Disorderly transition", respectively.

The carbon tax increases energy prices, based on the carbon content of each energy fuel. We take advantage of the estimated price variation provided by Faiella and Lavecchia (2021), which assess the effects of a carbon tax levied on Italian households. In particular, they use the carbon emission and the energy conversion factors for electricity, natural gas (as a proxy of heating fuels), gasoline and gasoil from official sources, such as ISPRA (2019) and Ministero dell'Ambiente (2019). Using 2018 prices as the baseline, they find that the introduction of a carbon tax of €50 per ton, is equivalent to adding a surcharge of €0.014 to each kWh of electricity (+6 per cent), €2.8 to each GJ of gas (+12 per cent) and €0.12 to each litre of gasoline or gasoil (+8 per cent). Overall, heating prices increase more, between 12 and 48 per cent, under a carbon tax of €50-200, and almost triple in case of a carbon tax of €800, followed by transport fuels (8-32 per cent for a carbon tax of €50-200) and electricity (6-25 per cent).

Similarly, for firms, the implied variations ranges from 15 per cent (for a €50 tax) to 230 per cent (for a €800 tax).

5.2 Households

A household is defined as financially vulnerable if its loan instalments to income exceed 30 per cent and its income is below the median of the population. Michelangeli and Rampazzi (2016) show that, with respect to the others, financially vulnerable households are more likely of being late in their loan payments by more than 90 days, which is the first stage of non-performing loans. This indicator is also highly correlated with the rate of the new non-performing households' loans based on the Central Credit Register data, which is measured as the flow of non-performing loans over the previous period stock of performing loans (Bank of Italy 2016). Because of these reasons, vulnerable households must be closely monitored to gain some insights on the threats to the stability of the financial sector stemming from them.

Mortgages represent the main liability of Italian households and, consequently, household financial vulnerability is closely tied with changes in loan

[12] *A Climate-Neutral EU by 2050*, Shell Climate Change, a blog by David Hone, 5 May 2020.

instalments associated with this type of debt, as reported in Michelangeli and Pietrunti (2014b). However, in light of the vast increase in consumer credit between 2014 and 2019, any consumer loans (including overdraft and revolving credit card) must be taken into account to properly identify financially vulnerable households. Indeed, Attinà et al. (2020) show that about half of vulnerable households have some kind of consumer credit and these loans represent a larger threat to financial stability when associated with mortgages.

This body of research evaluated so far how vulnerability changes in face of aggregate shocks to income (i.e. a recession) or interest rate (i.e. contractionary monetary policy). We build on them to assess the impact of a climate shock on the fragility of the household sector. In particular, to carry out this exercise, we introduce in the model a carbon tax, which reduces household disposable income in a heterogeneous way across households.

We use the results of (Faiella and Lavecchia, 2021) on the increase of expenditure induced by the introduction of the carbon tax for each group of households identified in the HBS as the combination of household types, their position in the expenditure distribution and their geographical location (108 subgroups or strata) and we join this information with the microdata of the Bank of Italy Survey on Household Income and Wealth (SHIW), using the same strata as a merging variable. We assume that household available income is reduced in proportion to the increase in the total energy expenditure driven by the carbon tax. This implies that the impact of the carbon tax is different across households in our sample depending on their energy preferences and consumption level. In particular, let the household income that accounts for a carbon tax τ defined as:

$$\tilde{y_{i,t,\tau}} = y_{i,t} + c_{i,t}(1 - d_{i,t,\tau}) \tag{6}$$

where $y_{i,t}$ is household income gross of financial charges and net of imputed rent, $c_{i,t}$ is household consumption, $d_{i,t,\tau}$ is an adjustment factor equal to the ratio of total consumption after the introduction of the carbon tax and total consumption before the carbon tax. In the baseline scenario, the carbon tax is equal to zero, which reflects the current fiscal Italian situation, and $d_{i,t,\tau}$ equals 1.

The indicator for household financial vulnerability $VHH_{i,t}$ is then defined as follows:

$$VHH_{i,t} = \begin{cases} 1 & \text{if } L_{i,t}/\tilde{y_{i,t,\tau}} > 0.3 \\ & \text{and } \tilde{y_{i,t,\tau}} < median(\tilde{y_{i,t,\tau}}) \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

where $L_{i,t}$ is household i total loan instalment (given by the sum of mortgage and consumer credit instalments) in year t, and $median(\tilde{y_{i,t,\tau}})$ is the median value of equalized income in the population in period t, adjusted to take into account of the effect of the carbon tax. Figure 1 shows the average effects of the introduction of a carbon tax on households' income by age. Households more exposed to the shocks are those aged 16-39: because of a less elastic energy demand, their total expenditure increase more dragging down their disposable income.

5.3 Firms

A firm is defined as vulnerable if its EBITDA is below zero or if the ratio of interest expenses to EBITDA exceeds 50 per cent. As shown in De Socio and Michelangeli (2017), vulnerable firms are more likely than others to default or exit from the market. This indicator is also highly correlated with the rate of new non-performing firms' loan based on the Central Credit Register data, which is measured as the flow of non-performing loans over the previous period stock of performing loans. As for the households, vulnerable firms require to be closely monitored because they can pose a threat to the stability of the financial system.

While De Socio and Michelangeli (2017) concentrated on assessing the risks associated with aggregate shocks to the EBITDA (e.g. a recession) or the interest rate (i.e. contractionary monetary policy), in this paper we assess how firms' financial vulnerability will vary in face of a carbon tax τ that has a heterogeneous impact of each firm EBITDA. That is, even if τ is the same across non-financial corporations, in practice, different firms have a different exposure to a climate shock depending on their sector of economic activity and size (as explained in Section 4.2).

The indicator for firm i's financial vulnerability $VNFC_{i,t}$ is then defined as follows:

$$VNFC_{i,t} = \begin{cases} 1 & \text{if } EBITDA_{i,t}(1 - x_{i,t,\tau}) < 0 \\ & \text{or } IE_{i,t}/(EBITDA_{i,t}(1 - x_{i,t,\tau})) > 0.50 \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

where $IE_{i,t}$ is firm i's interest expenses in period t and $x_{i,t,\tau}$ the percentage change in EBITDA of firm i as a consequence of the introduction of the carbon tax τ. In the baseline scenario, the carbon tax equals zero, reflecting the current situation in Italy.

Using the elasticities estimated in Section 4.2 we compute the effect on firms' energy costs caused by the introduction of τ and we can easily recover the counterfactual EBITDA considering the τ effect. This exercise considers only the short-term effect of the climate mitigation policy. In fact, in the medium-long run, firms could reduce the effect of τ on their EBITDA by (i) improving their energy efficiency; (ii) using energy sources excluded by this taxation (i.e. renewable); (iii) adjusting their prices to mitigate the impact of a carbon tax on their EBITDA.

Figure 2 shows the median effect on firms' EBITDA according to different sizes of carbon pricing. Agriculture emerges as the most hampered sector probably because their energy demand seems to be inelastic, causing a direct impact on energy cost and thus on firms' EBITDA. On the contrary, effects are quite negligible for construction, which turns out to be the sector with the highest demand elasticity.

6 Results

This Section describes the impact of a carbon tax on households' and firms' financial vulnerability.

Households - Panel A in table 3 shows the main results for the household sector. In the baseline scenario, which refers to the last available data from the SHIW (i.e. 2016), the shares of vulnerable households and of their debt equal 1.6 and 10.3 per cent, respectively. Introducing a carbon tax of moderate size (€50/tCO2) implies a 3.9 and 5.1 per cent increase in the two variables, which correspond to values higher by about 6 and 50 basis points with respect to the baseline (table A.1 in the Appendix). If the carbon tax would double in size (€100/tCO2), the two variables would increase by 5.3 and 5.9 per cent, reaching 1.69 and 10.95 per cent. The increase in vulnerability would be larger in face of a more sizeable carbon tax (€200/tCO2): under this adverse scenario, the percentage change with respect to the baseline scenario would be 8.7 and 12.3 per cent for the share of vulnerable households and for the debt at risk respectively, reaching 1.74 and 11.61 per cent. Finally, in case the highest carbon tax (€800/tCO2) was introduced, the impact on vulnerability would be more relevant and the share of vulnerable households and the debt at risk would increase by 11.8 and 17.6 per cent, to 1.79 and 12.2 per cent.

This exercise suggests that even a sizeable carbon tax would leave households' financial vulnerability contained and far below the peak reached during the sovereign debt crisis (when the shares of vulnerable households and of their debt reached 2.8 and 19.4 per cent, respectively).

Figure 3 presents results for the heterogeneity by age of the reference person and household size. The share of vulnerable households is higher among the younger, which however detain on the average smaller debt amount. A €50 carbon tax implies an increase in the share of vulnerable households by 30 basis points among those aged 16-39, while its impact is almost negligible for older households. Only the €800 carbon tax would have a relevant effect on households with a reference person aged 40-65 (with an increase in financial vulnerability by about 20 basis points). With respect to the debt at risk, the share is higher among households with heads aged 40-65 and equals about 11 per cent, but differences across age classes are not very pronounced. The various carbon taxes have also a similar impact across classes and the most extreme carbon tax would raise symmetrically the share of debt at risk by about 2 percentage points.

With respect to household size, financial vulnerability is higher among larger families. Nevertheless, the impact of carbon taxes for those households is very contained, reflecting their higher price elasticity. On the opposite, the share of vulnerable households is much lower among those with one or two components, but their debt at risk rises more in face of a carbon tax. Nevertheless, also for this group the overall effect remains very much contained.

Firms - Panel B in table 3 shows the main results for the corporate sector. In the baseline scenario, which refers to the last year for whom we have firms' balance sheets available from Cerved (i.e. 2018), the share of vulnerable firms and their debt equal 22.4 and 27.4 per cent respectively[13]. If we incorporate a €50 carbon tax the percentage change with respect to the baseline of two vulnerability indicators would be equal to about 45 and 10.7 per cent, reaching 32.5 and 30.3 per cent (table A.2 in the Appendix). If we account for a carbon tax double in size (€100), the two indicators would increase by about 48 and 12 per cent, to 33.3 and 30.6 per cent respectively. The increase in financial vulnerability would be larger in face of a more sizeable carbon tax (€200), as the share of vulnerable firms and the share of their debt would increase by 56 and 15 per cent with respect to the baseline scenario, reaching 35 and 31.4 per cent. Finally, if we consider the highest carbon tax (€800), the two indicators would rise by 92 and 24 per cent, to 43 and 34 per cent.

Figure 4 shows how the impact is heterogeneous across sectors and firm size. The share of vulnerable companies is particularly high for agriculture, where fragile firms are about 38 per cent in the baseline scenario. The impact of a €50 carbon tax is however quite similar across sectors, raising the share of vulnerable firms by about 10 percentage points. With respect to debt at risk, in the baseline scenario financial vulnerability is higher in the construction and energy sectors; for these two sectors, a €50 carbon tax would increase vulnerability by about 3.6 and 0.8 percentage points, to 48 and 52 per cent. The tax would have the largest impact on firms operating in manufacturing (increase in debt at risk by about 5 percentage points), which is the least vulnerable sector in the baseline.

With respect to size, financial vulnerability is higher among micro firms. The debt at risk equals 40 per cent of the one held by these firms in the baseline scenario and raises to 47 per cent when a carbon tax of €50 is introduced. An extreme carbon tax (€800) would raise debt at risk of micro firms to 54 per cent, below the peak of over 55 per cent reached in 2012.

7 Conclusions

In this paper, we carried out an exploratory analysis of the financial effects of a change in climate policy in Italy. We modelled the effects on the financial vulnerability of Italian households and firms due to a one-off carbon tax, considering four possible values to price one ton of $CO2$ (€50, €100, €200 and €800). Although a consensus on how to incorporate climate shocks in stress testing exercises has not been reached yet , most of the attempts to date use a macro approach. We instead propose a micro-founded model, which has several pros and cons.

[13]Differences with values published in the Bank of Italy, Financial stability report reflect the sample considered, as we cannot estimate the impact of a carbon tax on all firms submitting a balance sheet.

The strength of our approach lies in its very detailed representations of households and firms' heterogeneity. Indeed, we directly model the energy demand by considering the different fuel mix of each household/firm. Then, we translate the carbon tax directly into final energy prices according to their carbon content (for power we consider the average carbon intensity). Finally, using microdata, we can assess what type of household/firm is most exposed to this climate shock (sector, size, export propensity, position in the income distribution and so on). This helps us in identifying what Vermeulen et al. (2019) call "transition vulnerability factors"; in our case, indebted households with a young head of the family, small families with only one or two members, micro firms and companies in the manufacturing sector.

Our approach also has some drawbacks: it focuses on the short-term, and it is partial and static. In particularour analysis is based on partial equilibrium only: the spillover effects on other sectors are excluded. Finally, we do not take into account the dynamics: we consider a baseline year (2016 for households, 2018 for firms, because of data constraints) and we build a counterfactual world with the carbon tax in place. It also refers to pre-pandemic conditions, but we do not expect that the 2020 events would dramatically modify households and firms' response to a climate shock.

Moreover, we only consider a short-term effect of the carbon tax: there is no translation, no adaptation, and no appraisal of the possible recycling of the revenues. There is also some merit in focusing on the short term, given that uncertainty in policy responses to climate change and other shorter term vulnerabilities are likely to be the focus of businesses and financial institutions (Hansen, 2021).

Fully aware of all the limits, our idea is to use our approach to complement a fully-fledged "standard" stress test based on downscaled NGFS (2020, 2021) scenarios integrated with the NiGEM. Indeed, with our simulation, we have identified the most sensitive sectors or group of households (the aforementioned "transition vulnerability factors"). Moreover, we could link the share of vulnerable agents to the observed probability of default (PD) using regression techniques; shocks to income/EBITDA could then feed to our standard PD models (as in De Socio et al. 2020). This latter approach could be used to evaluate the compounding risks arising from COVID-19 and climate change.

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8 Tables and figures

	Households' short-run price elasticities			
	LS	Stratum-level LS	2SLS	Long-run
Electricity	-0.36***	-0.29*	-0.40***	-1.17***
Heating	-0.40***	-0.44**	-0.44***	-1.23***
Transport	-0.17**	-0.45**	-0.66***	-1.46***

Notes: p-values are reported in parenthesis. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Source: Faiella and Lavecchia (2021).

Table 1: Households' price elasticities

	Total Economy	Agriculture	Industry	Construction	Services
Total	-0.232***	0.0770	-0.397***	-0.583***	-0.116***
	(0.00)	(0.18)	(0.00)	(0.00)	(0.00)
0-49	-0.231***	0.0746	-0.393***	-0.577**	-0.120***
	(0.00)	(0.32)	(0.00)	(0.01)	(0.01)
>50	-0.208***	0.204*	-0.412***	-0.588***	-0.0141
	(0.00)	(0.06)	(0.00)	(0.00)	(0.75)

Table 2: Firms' price elasticities
Notes: p-values are reported in parenthesis. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

	Baseline	Percentage change wrt baseline Carbon tax per ton of CO2 €50	 €100	 €200	 €800
		A. Households			
Share of vulnerable HHs	*1.6*	3.9	5.3	8.7	11.8
Debt at risk	*10.3*	5.1	5.9	12.3	17.6
		B. Firms			
Share of vulnerable firms	*22.4*	45.0	48.2	55.6	91.6
Debt at risk	*27.4*	10.7	11.9	14.7	24.3

Table 3: Households' and firms' financial vulnerability

Notes: Baseline refers to the last available year of the data: 2016 for households and 2018 for firms. The share of vulnerable households and firms and the debt at risk are reported in percentage values.

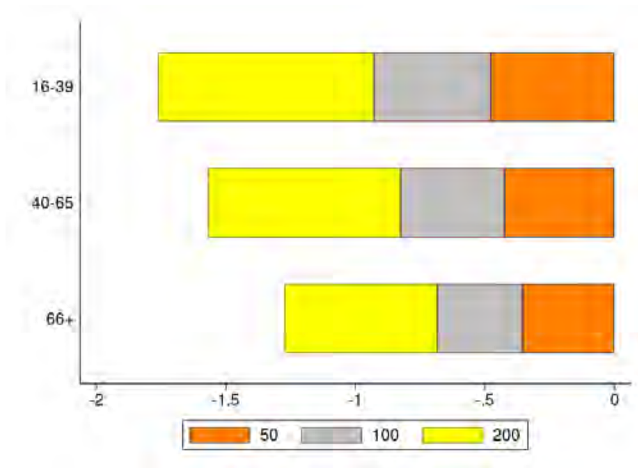


Figure 1: Carbon tax effects on households' income

Notes: The figure shows carbon tax average effects on HHs' income by the age of the head of the households. Results are reported as percentage changes wrt baseline.

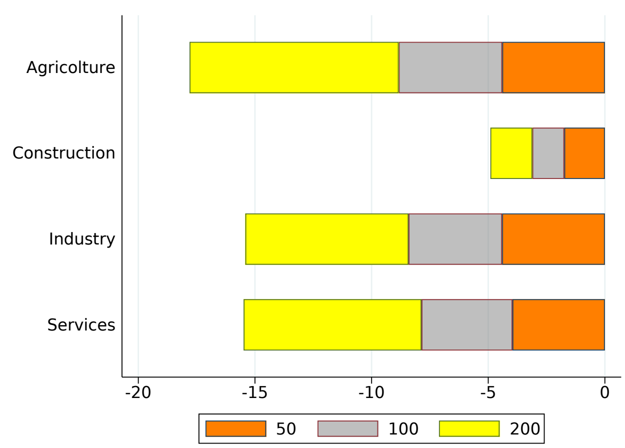
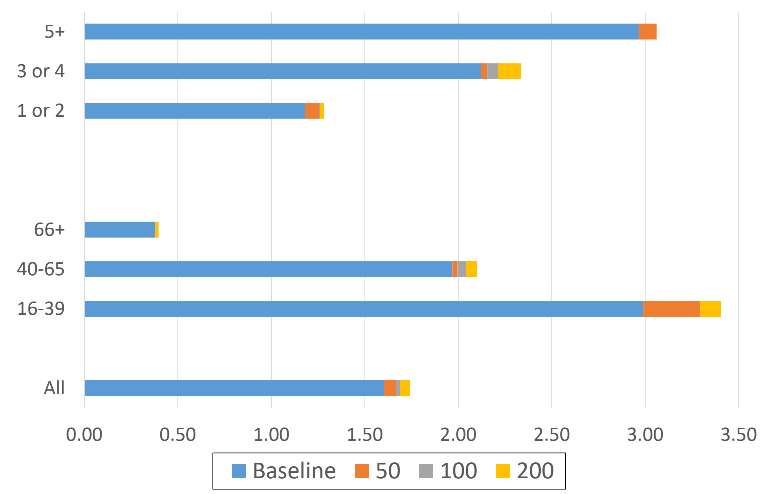
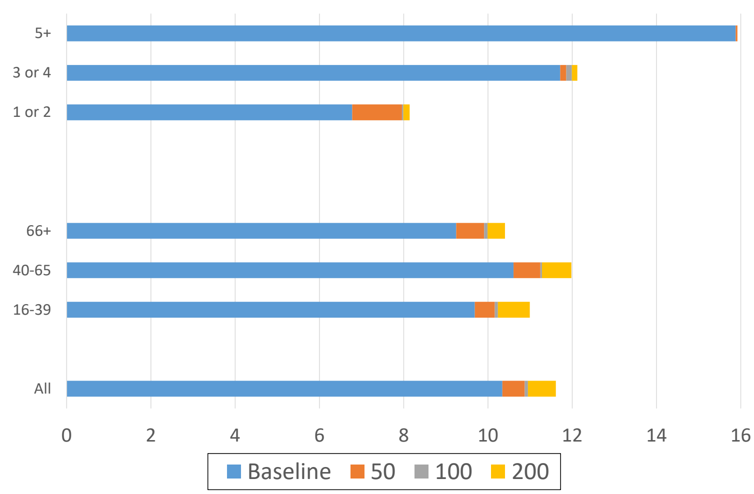


Figure 2: Carbon tax effects on firms' EBITDA

Notes: The figure shows carbon tax average effects on firms' EBITDA by the sector of economic activity. Results are reported as percentage changes wrt baseline.



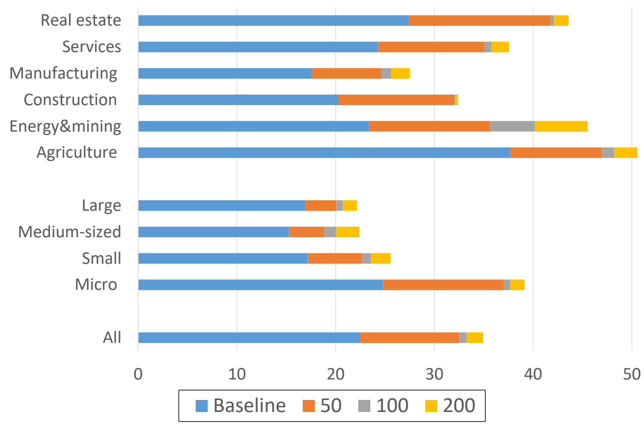
(a) Share of vulnerable households



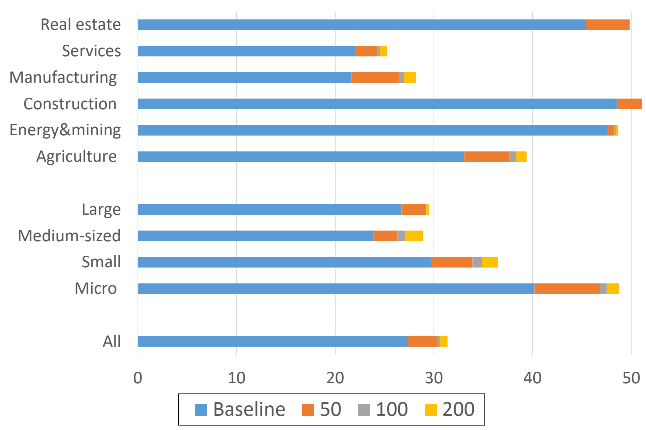
(b) Debt at risk

Figure 3: Heterogeneity in households' financial vulnerability

Notes: The figure shows the total vulnerable households and the heterogeneity with respect to age class and number of household components. Results are reported in percentage values.



(a) Share of vulnerable firms



(b) Debt at risk

Figure 4: Heterogeneity in firms' financial vulnerability

Notes: The figure shows the total vulnerable firms and the heterogeneity with respect to size and sector of economic activity. Results are reported in percentage values.

Appendix

A Additional tables

	Baseline	Carbon tax per ton of CO_2			
		€50	€100	€200	€800
	Share of vulnerable households				
Total	1.60	1.67	1.69	1.74	1.79
by age class					
16-39	2.99	3.29	3.29	3.40	3.52
40-65	1.97	2.00	2.04	2.10	2.18
66+	0.38	0.38	0.38	0.40	0.38
by number of household components					
1 or 2	1.18	1.26	1.26	1.28	1.29
3 or 4	2.12	2.16	2.21	2.33	2.47
5+	2.96	3.06	3.06	3.06	3.06
	Debt at risk				
Total	10.34	10.87	10.95	11.61	12.16
by age class					
16-39	9.69	10.16	10.24	10.99	11.69
40-65	10.61	11.24	11.28	11.98	12.51
66+	9.25	9.91	9.99	10.40	11.27
by number of household components					
1 or 2	6.78	7.96	7.99	8.14	8.38
3 or 4	11.72	11.86	11.99	13.23	14.17
5+	15.88	15.92	15.92	15.92	15.92

Table A.1: Households' financial vulnerability

Notes: Baseline refers to the last available year in the SHIW (2016). The share of vulnerable households and the debt at risk are reported in percentage values.

	Baseline	Carbon tax per ton of CO2			
		€50	€100	€200	€800
	Share of vulnerable firms				
Total	22.44	32.55	33.27	34.91	42.99
by size					
Micro	24.79	37.03	37.65	39.12	46.93
Small	17.20	22.65	23.56	25.56	34.49
Medium-sized	15.27	18.85	20.05	22.40	31.39
Large	16.93	20.07	20.73	22.16	28.34
by sector of economic activity					
Agriculture	37.68	46.95	48.18	50.54	62.69
Energy&mining	23.38	35.60	40.20	45.51	55.95
Construction	20.25	32.03	32.15	32.37	31.74
Manufacturing	17.56	24.62	25.58	27.50	34.67
Services	24.29	35.05	35.77	37.54	47.68
Real estate	27.40	41.79	42.12	43.59	53.05
	Debt at risk				
Total	27.37	30.31	30.62	31.38	34.01
by size					
Micro	40.20	46.86	47.50	48.76	53.98
Small	29.67	33.91	34.85	36.49	42.76
Medium-sized	23.89	26.32	27.13	28.88	35.42
Large	26.70	29.21	29.24	29.54	30.22
by sector of economic activity					
Agriculture	33.08	37.64	38.34	39.40	49.32
Energy&mining	47.52	48.31	48.45	48.69	49.22
Construction	48.52	52.14	52.24	52.40	51.96
Manufacturing	21.64	26.43	26.97	28.20	31.87
Services	22.02	24.29	24.53	25.24	28.02
Real estate	45.41	49.79	49.88	49.86	50.74

Table A.2: Firms' financial vulnerability

Notes: Baseline refers to the last available year of the Cerved data (2018). The share of vulnerable firms and the debt at risk are reported in percentage values.

B Imputation Procedure for firms' energy consumption

Information about energy consumption for industrial consumers is scarce. In recent years aggregate statistics (at industry level) are provided by official statistics through the Physical energy flow accounts (PEFAs),[14] but unfortunately more granular information is still lacking. To bypass this problem, we use an imputation procedure similar to that proposed in Faiella and Mistretta (2015).

Using the aggregated information about energy consumption (E), distinguishing different energy sources (z) in different sectors (s), we compute the per-worker (energy) consumption by using total workers $L_{s,z,t}$ provided in national accounts. The dataset used includes also information on employment at the firm level ($l_{i,s,t}$) from the INPS.

Let's define

$$e_{i,z,t} = l_{i,s,t} * \frac{E_{s,z,t}}{L_{s,z,t}}$$

where $e_{i,z,t}$ is the total quantity of a specific energy source consumed by firms.

We are aware that,in this way, within sectors variability depends only on the number of workers. However, given the lack of more detailed data, this is the best possible approach.

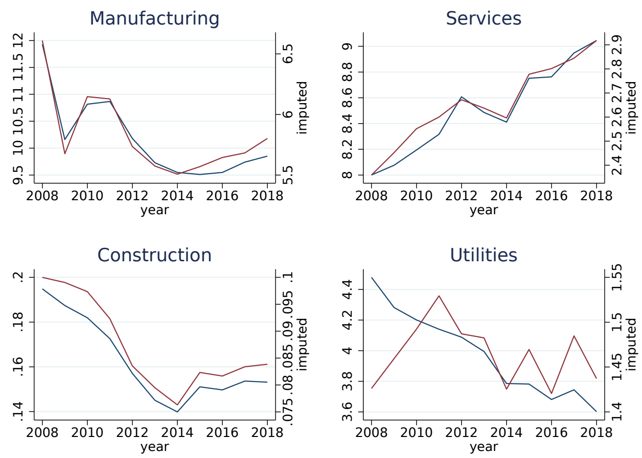
To check if the imputation gives a reasonable figure about firms' energy consumption, we propose a comparison between aggregated data and total imputed consummation.

Figure B.1 shows the aggregate consumption of electricity and gas by firms in our sample, as a result of the previous imputation, and the aggregate consumption according to official statistics. As shown, the sum of the imputed consumption series has the same dynamics as the official statistics. However, the total energy consumed in our dataset is lower with respect to that consumed in the whole economy; this reflects the fact that we use a representative sample instead of the total population.

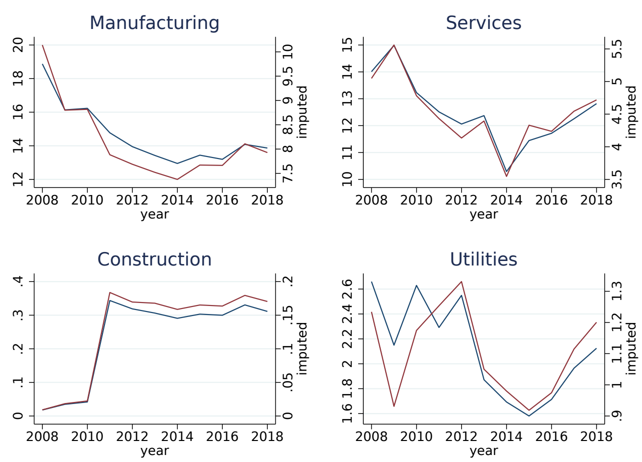
[14]PEFAs complement the traditional energy statistics, balances and derived indicators which are the main reference data source for EU energy policies and record the flows of energy within the economy.

Figure B.1: Firms' energy consumption

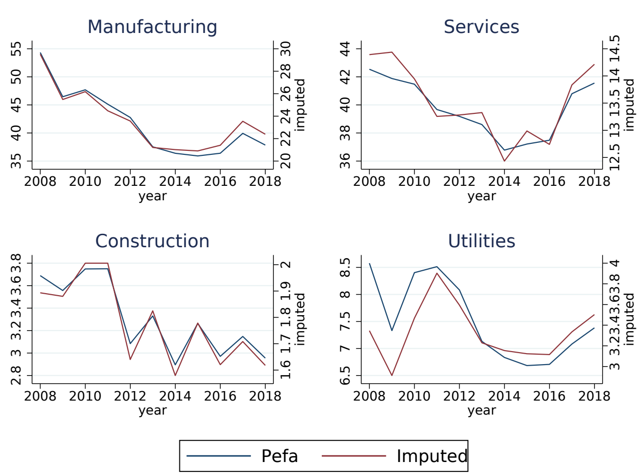
Notes: PEFA provide information on energy flows arranged in a way fully compatible with national accounts, and it refers to the total economy. Imputed quantities refer to the firms considered in the present analysis computed according to the procedure described in this Appendix.



(a) Electricity



(b) Gas



(c) Total Energy