The design of macroeconomic scenarios for climate change stress tests

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Abstract

The challenges of climate change affect all aspects of the economy, including financial stability, which may be affected both by the physical risks (associated with the climate change process itself) and the transition risks (associated with initiatives to curb the climate change process). This article presents a model designed to produce macroeconomic scenarios, chiefly related to transition risks, to serve as a basis for stress tests to verify that all the components of the financial system are prepared for possible adverse events of this type. In particular, these scenarios are based on a hypothetical rise in the price of CO_2 emission allowances, over a 2-5 year horizon. The model simulates the impact of this shock on the Spanish economy, paying particular attention to sectoral asymmetries arising from the intensity with which different types of energy are used in each industry, the interdependencies summarised in the input-output tables for the Spanish economy and the general equilibrium effects in terms of relative price changes and sectoral reallocation.

1 Introduction

The challenges of climate change affect all aspects of the economy, including financial stability. Both the physical risks and the transition risks may have asymmetric effects that reveal a special vulnerability in certain sectors or firms, so that under the most pessimistic scenarios, some financial institutions[1] may find themselves in difficulty if they are poorly diversified in these newly relevant dimensions. Bank stress tests attempt to anticipate the possible emergence of this type of problem. To carry out such tests, quantitative tools are required to simulate the effects of shocks and their transmission throughout the economy and financial system. This article presents one of the elements being prepared for these climate change stress tests: a sectoral model capable of generating macroeconomic scenarios to serve as the starting point of the exercise. As the model is still under development and the current objective is merely to begin to communicate the preparation process for these scenarios, this article only addresses the main features of the model and the type of results it can generate. In particular, no details are provided (for the time being) about the effects of the simulated shock on specific sectors.

Physical risks are those associated with the process of climate change. These include, inter alia, rising temperatures, ice melt and sea level rises, a higher frequency

1 These include not only banks, but also other financial intermediaries, such as insurance companies and investment funds, which are closely linked to banks in Spain. In principle, the scenarios generated by this model may be used to analyse the effects of the shock on all of them.

and intensity of adverse atmospheric phenomena, progressive degradation of environmental variables, such as air and water quality, deforestation and biodiversity loss.[2] These risks are already beginning to materialise, causing significant damage (to capital goods and real estate, for example), reductions in productivity and ad hoc disruptions to production chains. They can be expected to continue increasing for decades, so that the most adverse effects will be concentrated in the long run.

Transition risks, on the other hand, are those associated with initiatives to stop the climate change process: raising the cost of emission allowances, new taxes and subsidies to accelerate reductions in greenhouse gas emissions, new regulations requiring changes in agents' behaviour to obtain these results, technological changes that increase the rate at which capital is depreciated when replaced by less polluting options, or even consumer preference changes prompting a producer response, etc. In the political sphere, the development of climate change legislation also affects financial institutions: for example, the European Commission's "Action Plan: Financing Sustainable Growth" seeks to redirect capital flows towards sustainable investment, and the Taxonomy Regulation, also approved by the European Commission, defines the criteria for classifying economic activity environmentally. Legislative developments may also affect financial institutions' asset portfolios, including the EU Green Bond Standard, which will potentially have an impact on asset valuations, the inclusion of environmental aspects in the European Central Bank's (ECB) bank stress tests, and, more generally the ECB's mandate review.[3] In the case of physical risks, the greatest danger is that actions end up being insufficient to change the current course of climate change and avert the most pessimistic scenarios in the long term. This extended time frame should mitigate the implicit risks to financial stability, allowing institutions to adapt their exposure to different firms and sectors smoothly over time; even so, given the potential extent of these risks, they will also need to be evaluated quantitatively. In the case of transition risks, however, there is a greater probability of observing potentially sizeable effects within more limited time periods, especially if a disorderly transition amplifies the short-term costs.[4]

The model presented in this article is designed to produce macroeconomic scenarios, chiefly relating to transition risks, to serve as the basis for stress tests to verify that every part of the financial system is prepared for possible adverse events of this type. In particular, these scenarios will be based on a hypothetical rise in the price of CO_2 emission allowances, within a horizon of 2 to 5 years. The model simulates the impact of this shock on the Spanish economy, paying particular attention to sectoral asymmetries arising from the intensity with which different types of energy are used in each industry, the interdependencies summarised in the input-output

2 Various European and international bodies have published evidence on the long-term physical impact of climate change. See OECD (2015), G20 (2016), ECB (2019) and European Commission (2020).

3 See ECB (2021).

4 See Bank of England (2018), ESRB (2016) and ECB (2019).

tables for the Spanish economy, and the general equilibrium effects in terms of relative price changes and sectoral reallocation.[5]

Section 2 details the main characteristics of the model in question, while Section 3 discusses the preliminary simulation results and Section 4 presents sensitivity exercises for these results. Lastly, Section 5 sets out the conclusions.

2 A sectoral general equilibrium model of the Spanish economy

The banking sector stress tests take as their starting point macroeconomic scenarios designed to reflect the possible behaviour of the economy in the event that large negative shocks materialise. In later stages, the aggregate variables these scenarios provide are used to estimate their effect on bank loan portfolios and balance sheets. The scenarios are usually prepared using traditional macroeconomic models, such as the Quarterly Macroeconometric Model of the Banco de España (MTBE),[6] which summarises the historical relationships between the main variables of the Spanish economy, e.g. between firms' investment and the demand or interest rates they face, or between household consumption and real disposable income or the unemployment rate. That model is a general one, capable of simulating a large variety of possible shocks. However, it does not contain the necessary ingredients to prepare a scenario that adequately reflects the transition risks. This requires a detailed sectoral breakdown and specific details of the energy use and emissions intensity in each industry.

To fill these gaps, a new macroeconomic model has, in recent months, begun to be designed specifically to generate these scenarios. The model is still not complete, but, as in the case of the MTBE, it probably never will be; instead it will be subject to a constant process of renewal and enhancement to adapt it to events and needs as they arise. The main features of this model are outlined below. Within the next few months, the Banco de España will publish an occasional paper providing more technical details of the specification of the current version of the model.[7]

Inspired by previous developments in the literature,[8] the model is a general equilibrium one in which agents adjust their decisions according to those of all the other agents. In particular, prices and quantities are optimally adjusted, following the prescriptions derived from the optimisation problem described for the various model agents (inter

5 The current model features very rich heterogeneity as regards sectors and input-output table links. However, the current version does not have capital or financial frictions, nor is the banking sector explicitly modelled, which could be an additional feedback channel. This extension is left for the future. Also, the model focuses on cross-sector heterogeneity, since it is especially relevant to explaining the different impact of transition risks. There may be other levels of intra-sectoral or geographical heterogeneity that are also relevant (as found, for example, by Bolton and Kacperczyk (2020)), but they are not reflected in this model and are not explored in this article.

6 See Arencibia, Hurtado, De Luis and Ortega (2017).

7 See Aguilar, González and Hurtado (2021).

8 See, for example, Bouakez, Rachedi and Santoro (2020).

Table 1
SECTORS CONSIDERED BY THE MODEL

Non-energy sectors	
1 Crop and animal production	27 Other wholesale trade
2 Forestry and logging	28 Other retail trade
3 Fishing and aquaculture	29 Land transport
4 Mining and quarrying	30 Water transport
5 Manufacture of food, beverages and tobacco products	31 Air transport
6 Manufacture of textiles, wearing apparel, leather	32 Warehousing & support activities for transportation
7 Manufacture of wood and wood products, except furniture	33 Postal and courier activities
8 Manufacture of paper and paper products	34 Accommodation and food service activities
9 Printing and reproduction	35 Publishing activities
10 Manufacture of chemicals and chemical products	36 Motion picture, video, television, music and radio
11 Manufacture of pharmaceutical products	37 Telecommunications
12 Manufacture of rubber and plastic products	38 Computer programming and information services
13 Manufacture of other non-metallic mineral products	39 Financial services, except insurance and pensions
14 Manufacture of basic metals	40 Insurance and pension funding
15 Manufacture of fabric. metal products, exc. mach. & equip.	41 Auxiliary activities to financial services
16 Manufacture of computer, electronic and optical products	42 Real estate activities
17 Manufacture of electrical equipment	43 Legal and accounting activities
18 Manufacture of machinery and equipment	44 Architectural and engineering activities
19 Manufacture of motor vehicles	45 Advertising
20 Manufacture of other transport equipment	46 Other professional services
21 Manufacture of furniture; other manufacturing	47 Administrative services
22 Repair and installation of machinery and equipment	48 Public administration and social security
23 Water collection, treatment and supply	49 Education
24 Sewerage & waste collection, treatment & disp. activities	50 Health
25 Construction	51 Other service activities
26 Wholesale and retail trade and repair of motor vehicles	
Energy sectors	
52 Manufacture of coke and refined petroleum products	53 Electricity, gas, steam and air conditioning supply

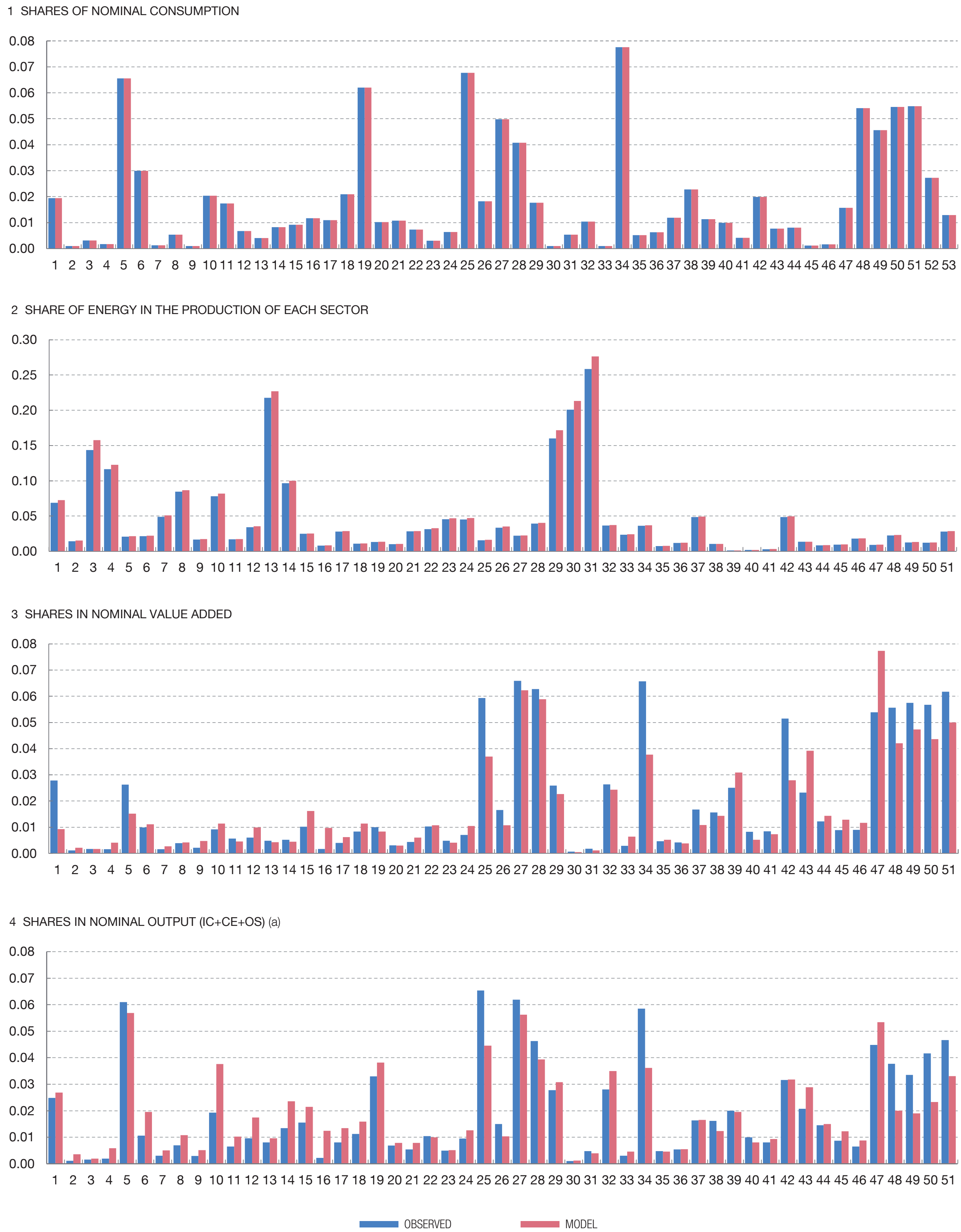
SOURCE: Devised by the authors

alia, consumers, producers and retailers). This is the main reason for the difficulty of computing the model equilibrium: it is necessary to find the set of prices and quantities for all sectors that simultaneously ensures that all agents are at their optimal point and that all the aggregate constraints of the economy are satisfied (the supply of each product coincides with its demand, the labour firms demand is equal to the supply by households, etc.).

One of the main features of the model is its detailed sectoral breakdown. Given that the risks associated with climate change have a very marked asymmetric component in this respect, it is essential for the model to be capable of capturing the different share of energy in the production functions of the various industries, and the interrelations between them. Table 1 sets out the sectoral breakdown currently used by the model:

Chart 1

MODEL CALIBRATION: SECTORAL DATA ADJUSTMENT



SOURCE: Authors' calculations, based on Eurostat data.

a IC stands for intermediate consumption, CE for compensation of employees and OS for operating surplus.

51 non-energy sectors and two energy production sectors ("fuels" and "electricity"). Chart 1 shows how the model calibration precisely replicates the share of each sector in household consumption and reasonably approximately (but not exactly, owing to the simplifications involved in the stylised form of the aggregator and production functions) the share of energy in the inputs of the various non-energy sectors, and the relative size of the various industries in terms of value-added and output.

The two energy sectors differ as regards the amount of emission allowances associated with each, and also in the way in which the simplified specifications of the model relate to the more complex real world structures.

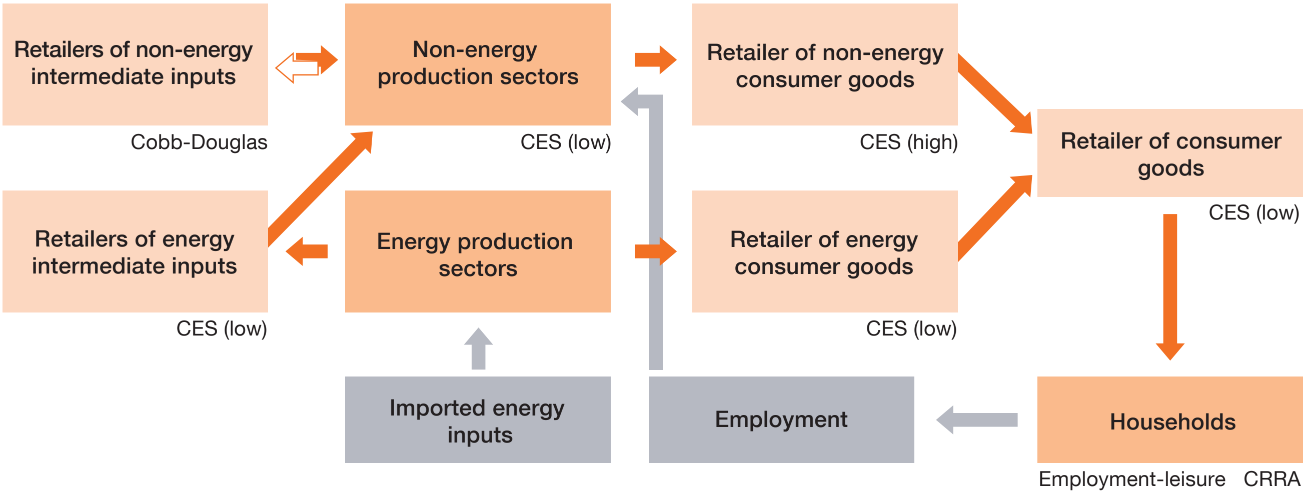
In the case of fuels, their production does not generate a large amount of emissions, but their use does; it is the agents who use the fuels that have to acquire the associated emission allowances, while the fuel producer receives a price that does not include the amount corresponding to such allowances. Electricity, in contrast, generates emissions when it is produced, but not necessarily when it is used. Thus, electricity users do not need to acquire emission allowances, but simply pay a price to electricity producers, who are responsible for obtaining the necessary emission allowances to be able to produce that electricity.

In contrast to these real-world idiosyncrasies, in the simplified structure of the model both sectors function in the same way: energy users pay a gross price that includes the electricity or fuel itself along with the necessary emission allowances to produce or consume it, and energy producers receive a net price from which the cost of these emission allowances has already been deducted. The fitting of the model to the data resolves this divergence between the real-world and model structures: the fuel price in the real world corresponds to its net price in the model, while the electricity price in the real world corresponds to its gross price in the model.

The difference between the gross price and the net price in the model is generated by a tax rate associated with the emissions, which is calibrated with the data available for the Spanish economy in the input-output tables and in the industry CO_2 atmospheric emission accounts published by the INE (National Statistics Institute). For electricity, the tax rate is obtained from the relationship between the value of the emission allowances used by the electricity production sector and the sectors' aggregate revenues, net of these allowances. In the case of fuels, the tax rate is estimated by means of the relationship between the value of the emission allowances used by all sectors, other than the electricity sector, and the sector's aggregate revenues, net of the allowances it uses. The result is a much higher tax rate associated with fuels than with electricity, corresponding to the higher level of emissions generated by the production and use of the former.

Figure 1 summarises the structure of the model very succinctly. In the lower right-hand corner, households choose optimally between consumption and leisure in order to maximise a utility function with constant relative risk aversion; that choice

Figure 1
SUMMARY REPRESENTATION OF THE MODEL STRUCTURE



SOURCE: Devised by the authors.

will depend on the level of consumption and the relationship between the aggregate price and wages. On the right-hand side of the figure, these households purchase a homogeneous good from the consumption retailer, who combines energy and non-energy consumer goods by means of an aggregator function with constant elasticity of substitution. Each of these two consumer goods is obtained, in turn, from a retailer who aggregates the different kinds of energy and non-energy goods by means of the corresponding CES (constant elasticity of substitution) aggregator function. And on the left-hand side, there are another 51 retailers of non-energy intermediate products with a Cobb-Douglas aggregator function (equivalent to a CES function with unit elasticity), and 51 retailers of energy intermediate products with a CES aggregator function, who combine the different products in order to sell the basket of energy or non-energy intermediate products used by each of the non-energy production sectors. In addition to these two baskets of intermediate products, the non-energy producers also use employment, combining the three elements by means of a nested CES production function. The energy producers in the model use a much simpler technology: the only input they use is basic energy products, imported at an international price that does not depend on actions taken in the domestic economy (in particular, this price should not change when the tax rate associated with emissions is raised in the simulation).

The different aggregator and production functions contain numerous parameters that allow the degree of substitution between goods to be controlled. In general, almost all of them are calibrated at values smaller than one, indicating that some – albeit limited – substitution between goods is to be expected in response to the simulated shock. This is true for substitution between fuels and electricity, both in the case of consumer goods and in that of intermediate products. The value of these elasticity of substitution parameters must be adjusted to the simulation horizon: a rise in the price of emission allowances would not be expected to lead to significant substitution between fuels and electricity in the road transport sector within a 3-year period, but could be expected to within 15 years. Among the various non-energy intermediate products, substitution is one-for-one (Cobb-Douglas aggregator), which means that the quantities react proportionately to the relative-price changes, so that the nominal weight of the different sectors in the basket of intermediate products acquired by each non-energy producer remains constant.[9] The only elasticity of substitution calibrated with a value greater than one is that of the retailer of non-energy consumer goods: households may substantially adjust how they distribute their consumption among the different categories of non-energy goods when their relative prices change.

In total, 159 agents interact with one another in the model:

— 1 representative household.

— 51 non-energy producers, who use employment, a basket of different energy intermediate products and a basket of different non-energy intermediate products.

— 2 energy producers, who use imported basic energy products.

— 1 consumption aggregator, who combines two products (energy and non-energy products).

— 1 energy consumption aggregator, who combines two products (fuels and electricity).

— 1 non-energy consumption aggregator, who combines 51 products (those produced by each of the non-energy sectors).

— 51 energy intermediate product aggregators, each of which combines 2 energy products (fuels and electricity).

— 51 non-energy intermediate product aggregators, each of which combines 51 non-energy products.

Computing the model equilibrium requires finding the 159 prices and the almost 3,000 quantities that simultaneously satisfy the optimality conditions of all these agents and the economy's aggregate constraints.

9 This level of substitution may be too high for simulations with a short time horizon, so that in future it may be desirable to replace these Cobb-Douglas aggregators with aggregators with a constant elasticity of substitution of less than one. However, given the large number of variables in this block of the model, the computational complexity of the exercise would increase substantially. The result would be a (non-homogeneous) widening of the sectoral differences in the simulation (greater impact in almost all sectors that already have especially negative effects).

3 A simple simulation exercise

The model described in the previous section can be used to estimate the effects of a rise in the price of CO_2 emission allowances. The results will take into account the Spanish economy's production structure (summarised in the input-output tables) and the general equilibrium effects in terms of relative price changes and sectoral reallocation in production and consumption alike.

In the simulation exercise presented below, the results of which are still very provisional, the shock consists of a substantial increase in the tax rate that represents the cost of CO_2 emission allowances in the model. The price of these allowances increased approximately fivefold between summer 2017 and summer 2019, largely as a result of regulatory changes designed to reduce excess supply in the market and generate greater incentives to reduce emissions, by means of reductions in the amounts supplied in allowance auctions and the launch of the Market Stability Reserve (MSR) which began to operate in January 2019. As an example of a possible intensification of these transition risks, the simulation estimates the impact of a further increase of similar magnitude, from €33 per tonne of CO_2 emitted (the market price at the beginning of 2021) to €165 per tonne.

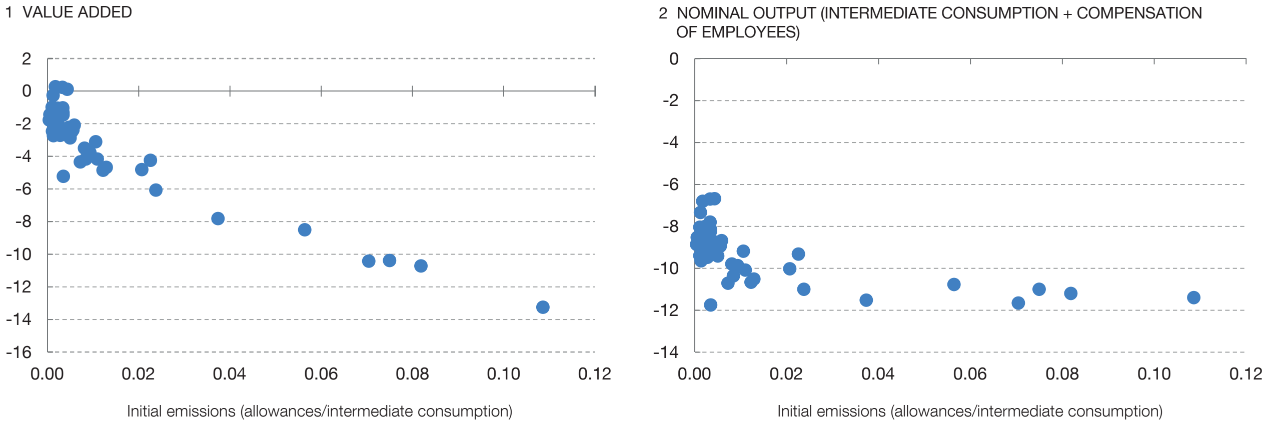
Under a relatively standard calibration, this shock gives rise in the model to a sharp reduction in the use of energy in consumption and production alike. This reduction is greater in the case of fuels, the use of which is reduced by 34%, than in that of electricity (down 19%), which is less emissions intensive.

The aggregate effects of the shock are negative: employment falls by 2.3% and real GDP by 3%. However the cross-sector dispersion is high: some sectors suffer much more severe falls than the average, while a few are even favoured. In general, the sectors most prejudiced by the increase in emission costs are the most energy-intensive ones, but significant non-linear second-round effects are observed in the simulation. Thus, there are sectors with relatively similar emission shares that are affected very differently, depending on the other sectors with which they are most interrelated. A sector that generates limited emissions may be strongly affected if it uses many intermediate products from energy-intensive sectors (their costs increase) or if a significant portion of its sales are to such sectors (their demand falls). Calibration of the model with input-output table data for Spain ensures that these relationships are realistically captured.

Chart 2 shows the relationship between the level of emissions of each non-energy sector and the impact of the simulation, in terms of real value-added and output. The energy sectors, which are not shown in these charts, are clearly the ones most affected. Since the results are still preliminary and will be revised in future, the chart does not indicate which observations correspond to which sectors.

Chart 2

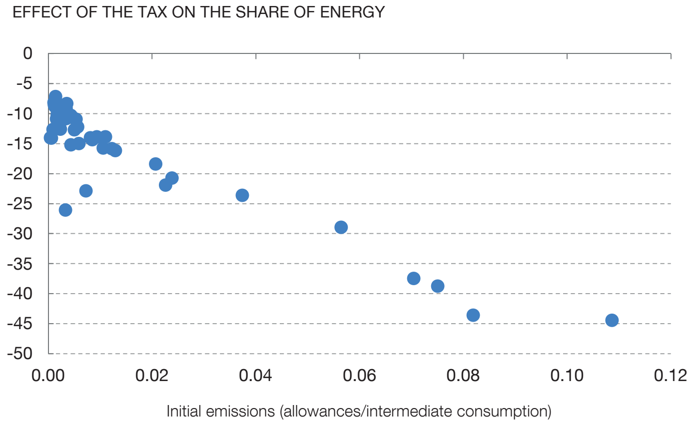
EFFECT ON THE VARIOUS SECTORS OF THE INCREASE IN THE COST OF EMISSIONS



SOURCE: Authors' calculations, based on Eurostat data.

Chart 3

EFFECT OF THE INCREASE IN THE COST OF EMISSIONS ON ENERGY INTENSITY



SOURCE: Authors' calculations, based on Eurostat data.

In response to the shock, all the productive sectors substantially reduce the amount of energy they use, but the effect is strongest in the most polluting sectors, which not only reduce their output to a greater extent, but also make larger cuts to the share of energy in the set of intermediate products they use. This result is illustrated in Chart 3.

Aggregate household consumption also falls considerably. This decline in consumption is seen in practically every sector (see Chart 4), but the fall is most marked in those products that become relatively more expensive in response to the shock.

Overall, the simulation generates the results expected, in the sense that the sectors most prejudiced by the increase in the price of emission allowances are those with the highest emissions, but it also has interesting non-linear effects, associated with the interrelations between sectors reflected in the input-output matrix.

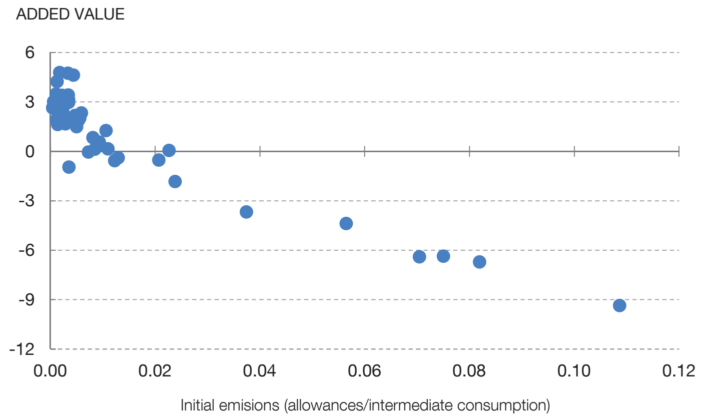
4 Sensitivity of the results to changes in some parameters

Especially as regards their quantification, the results of the simulation presented in the previous section depend crucially on the broad set of parameters with which the model is calibrated and the structures represented therein. This section presents two sensitivity exercises around the baseline simulation: first, the way in which the emission-cost increase is implemented is changed; and second, the parameters that regulate the degree of product substitution in firms' production functions and in consumers' utility function are modified.

In the version of the model used in the previous section, agents are refunded the cost of emission allowances through lump-sum transfers to households, a simple way of approximating any real-world mechanism in which the allocation of emission allowances and the effects on household income do not depend on households' future actions. This assumption gives rise to a particularly pessimistic scenario: regulatory changes may also be implemented so that the higher cost of emissions generates an increase in government revenues that allows the negative shock arising from the increase in emission costs to be offset by other tax changes that may partly mitigate its negative effects. Given that the aim of these simulation exercises is to generate macroeconomic scenarios that serve as a starting point for the performance of climate-change stress tests for the banking sector, it is reasonable to use assumptions that amplify the negative effects of the shock. However, this is not necessarily the most likely scenario.

Chart 5 presents the results of an alternative simulation in which the regulatory change is implemented in such a way as to minimise transition costs: the cost of emissions is raised by means of a tax that increases government revenues, allowing other distorting taxes to be reduced (in this case, the tax on household wage income). This affects the household choice between leisure and work, generating a positive supply-side shock (an increase in labour supply) that combines with the negative one (associated directly with the increase in emission costs). Depending on the calibration of the wage elasticity of labour supply, the net result may be, as in this simulation, expansionary: both employment and GDP increase, the negative impact on the sectors that generate most emissions is reduced and a considerable number of industries are benefited by the shock. These industries generate limited emissions and do not heavily depend, either through their purchases or sales, on sectors that generate large emissions, so that they are not significantly affected by the increase in emission costs, although they are benefited by the higher labour supply (and by a

Chart 5
ALTERNATIVE SIMULATION WITH REDUCTION OF TAXES ON LABOUR INCOME



SOURCE: Authors' calculations, based on Eurostat.

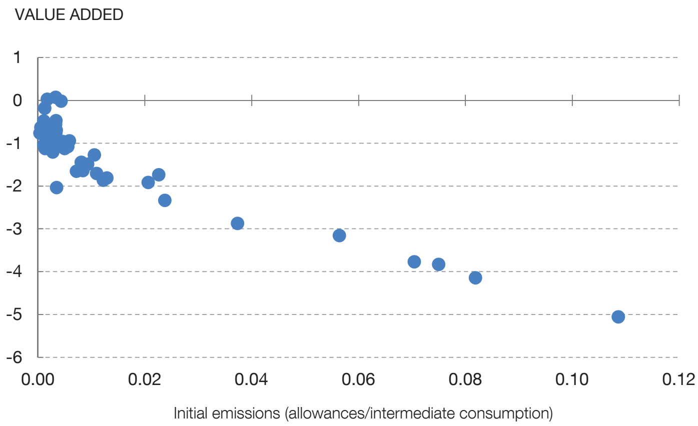
fall in their prices relative to other sectors, which was already present in the simulation in the previous section).

As compared with the fall of 34% and 19% in the use of fuels and electricity under the baseline simulation, this scenario with reduced taxes on employment income generates somewhat lower reductions of 29% and 13%. However the cost in terms of employment and GDP is completely eliminated, which means it is possible to implement a larger increase in emission costs until the same emissions-reduction effects are achieved, without the economic costs at aggregate level (although there are still significant negative effects for some sectors).

A second dimension in which sensitivity exercises need to be performed is that of the elasticities of substitution between goods. As mentioned in the previous section, the sectors most affected by the increase in emission costs are those most dependent on the use of fuels. In the long-term, the elasticity of substitution between types of energy will be higher, allowing these sectors to substitute, to a greater extent, electricity for fuels, or inputs that require less energy for those that use a large amount of energy. In any event, the CO_2 emissions associated with their productive processes will be cut and, therefore, the contractionary effect of the shock reduced. The results of an alternative simulation with a higher elasticity of substitution are shown in Chart 6.

This higher elasticity of substitution reduces the sectoral heterogeneity, giving rise to a more uniform effect across sectors. The sectors that were prejudiced in the baseline simulation are still the ones that decline most in this version with a higher elasticity of substitution, and the sectors benefited are also still the same ones, but

Chart 6
ALTERNATIVE SIMULATION WITH HIGHER ELASTICITY OF SUBSTITUTION



SOURCE: Authors' calculations, based on Eurostat data.

the difference between the former and the latter is significantly reduced. When this scale difference is corrected, the shape of the cloud of dots is similar but not identical to the original: the change in the elasticity of substitution generates moderately non-linear effects which depend on the productive structure and sectoral interrelations.

5 Conclusions

Both climate change and the policies implemented to counter it may have negative effects on the economy, which would be transmitted to financial institutions through their exposure to the firms and sectors most affected. These risks should be assessed with a view to mitigating and preventing their impact on financial stability. For this purpose, various institutions, including the Banco de España, have begun to prepare climate-change stress tests for banks, to identify actions to reduce the probability of the most unfavourable events.

As an initial ingredient, such stress tests require macroeconomic scenarios that capture the effect on the economy of possible adverse shocks. This article has presented a model specifically designed to build such scenarios. The model focuses on the transition risks, associated with the regulatory measures applied to check climate change, as these are the most important ones over relatively short time horizons. And since the effects of these risks are foreseeably highly asymmetric across sectors, the model is highly granular and stresses the interrelations described by the input-output tables for the Spanish economy and the general equilibrium effects in terms of relative-price changes and substitution between intermediate products in firms' production functions, and between types of consumption in the household utility function. Physical risks (arising from climate change itself) remain for a subsequent development, which will require a different model, more focused on the long term and probably less sectorally disaggregated.

This article has presented a still-preliminary version of this sectoral model for transition risks. In the short term, the focus will be on improving the model to fit other aspects of the observed data and on increasing the flexibility of the options for the parameters defining the elasticity of substitution between goods in the various aggregator, production and consumption functions. Further ahead, the model could be expanded to convert it into an open economy model, with exports and with imports in addition to those of basic energy goods, and to include capital in the production function, enhancing the realism with which the model fits the data and allowing effects on assets used by firms as loan collateral to be incorporated into the simulations.

Even in its current simpler version, the model already quite closely approximates the productive structure of the Spanish economy and allows reasonably realistic simulations to be formulated, in which the sectors most affected by a rise in the price of emissions are those that use energy inputs more intensively, while at the same time reflecting the non-linear effects generated by the interrelations between sectors in a general equilibrium structure.

The model allows certain key factors for designing policies to combat climate change to be identified and, in particular, highlights the importance of designing fiscal instruments and regulatory mechanisms to achieve emission reduction objectives at the lowest possible economic cost. Notwithstanding this, the results of the simulations also show that, even in the best scenarios, risks remain for certain sectors that would be prejudiced by a disorderly transition, even if environmental policies are implemented through tax structures that include compensation to eliminate adverse effects at the aggregate level. The climate change stress tests for banks will attempt to ensure that the financial stability risks associated with these shocks are minimised.

REFERENCES

Adrian, T., N. Boyarchenko and D. Giannone (2019). "Vulnerable Growth", *American Economic Review,* 109(4), pp. 1263-1289.

Aguilar, P., B. González and S. Hurtado (2021). "A sectorial model for carbon tax stress test scenarios», *Working Papers,* Banco de España, forthcoming.

Arencibia, A., S. Hurtado, M. de Luis and E. Ortega (2017). "New version of the Quarterly Model of Banco de España (MTBE)", *Occasional Paper* No 1709, Banco de España

Bank of England (2018). *Transition in thinking: The impact of climate change on the UK banking sector,* Report of the Prudential Regulation Authority, September.

Bolton, P., and M. T. Kacperczyk (2020). "Do Investors Care about Carbon Risk?" National Bureau of Economic Research (NBER), *Working Paper* No 26968.

Bouakez, H., O. Rachedi and E. Santoro (2020). "The Government Spending Multiplier in a Multi-Sector Model", R&R, *American Economic Journal: Macroeconomics.*

European Central Bank (2019). "Climate-related risks to financial stability", special feature B, *Financial Stability Review,* May.

European Central Bank (2021). "Climate change and central banking", speech by Christine Lagarde, President of the ECB, 25 January.

European Commission (2020). *Climate change impacts and adaptation in Europe,* JRC PESETA IV final report.

European Systemic Risk Board. *Too late, too sudden: Transition to a low-carbon economy and systemic risk,* report No 6 of the Advisory Scientific Committee, February.

G20 (2016). *G20 Green Finance Synthesis Report*, G20 Green Finance Study Group, September.

Organisation for Economic Co-operation and Development (2015). *The Economic Consequences of Climate Change,* OECD Publishing, Paris, November.