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Abstract

The use of scenario analysis for climate-related financial risks is progressing in various jurisdictions. In this paper, we conduct a top-down scenario analysis of transition risk for Japanese banks. We analyze a short-term (5-year) scenario, while long-term scenarios of about 30 years are often used in climate-related scenario analysis. In our analysis, we examine two cases regarding the extent to which firms adjust smoothly to carbon price increases: a smooth adjustment case and a slow adjustment case. In addition, we use a multi-sector dynamic general equilibrium model to account for inter-industry spillovers.

There are two main findings of this paper. First, we find that the degree of firms' adjustment has substantial effects on credit cost ratios of banks. This suggests the importance of accounting for the degree of adjustment to carbon price increases. Second, we find that the carbon price increase not only has an impact on the directly affected key sectors, but also spreads indirectly to other sectors through inter-industry linkages, resulting in an increase in the credit cost ratio. This suggests that even regional banks with relatively small exposure to key sectors need to pay close attention to the transition risk.

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1. Introduction

An increasing number of financial authorities, acknowledging its usefulness, employ scenario analysis to assess climate-related financial risks[1]. In June 2022, the Basel Committee on Banking Supervision (BCBS) published "Principles for the Effective Management and Supervision of Climate-related Financial Risks" to improve practices in managing climate-related financial risks (BCBS, 2022). The BCBS regards scenario analysis as a tool that financial authorities should consider applying to identify climate-related risk factors and measure portfolio exposures. In the meantime, the Network for Greening the Financial System (NGFS), an initiative by central banks, published climate scenarios in 2020 and has been refining and expanding the scenarios ever since[2]. In this context, a study by the Financial Stability Board (FSB) and the NGFS (FSB/NGFS, 2022) reports that the number of scenario analyses conducted by financial authorities increased from 4 to 35 over about a year, with 31 analyses either in progress or under consideration. The use of scenario analysis is rapidly spreading around the world.

Scenario analysis examines the impact on the real economy and financial system of an increase in the carbon price to achieve a long-term temperature increase target[3]. For this reason, many of the analyses conducted so far are based on the scenarios of the NGFS and set a long time horizon of about 30 years for the analysis, while covering both transition and physical risks (FSB/NGFS, 2022)[4]. The advantages of adopting a long time

[1] The use of scenario analysis is increasing not only among authorities but also among financial institutions. This is largely due to the publication of recommendations by the Task Force on Climate-related Financial Disclosures (TCFD), which recommended the use of scenario analysis to analyze climate-related risks and opportunities, and to the role played by private sector initiatives such as the United Nations Environment Programme Finance Initiative (UNEP FI) and the Glasgow Finance Alliance (GFANZ). Looking at the efforts of Japan's financial institutions, the three mega banks and other major banks have been pioneers in publishing quantitative results, and a growing number of regional banks have also begun scenario analysis. For more information on regional banks' efforts to address climate-related financial risks, refer to Financial System and Bank Examination Department of the Bank of Japan (2023).

[2] The NGFS has developed climate scenarios in collaboration with external research institutions that develop Integrated Assessment Models (IAMs), and since the first version was published in 2020, the scenarios have been refined and expanded. While there are alternative types of IAMs, the kind of IAMs adopted by the NGFS relates to different modules, such as a climate and energy system module and a socio-economic module, by carbon prices and evaluates their interactions. For more information on IAMs and their use in scenario development, see Takeyama et al. (2023).

[3] There are several possible carbon pricing schemes, including emissions trading, carbon taxes, and carbon credits. While the mechanisms of the schemes differ, they all have in common the idea of putting a price on carbon emitted by economic agents and controlling their emissions. Although this paper assumes a carbon tax for the sake of convenience, the same results would be obtained if carbon prices were raised under other schemes.

[4] For example, Europe (ECB (European Central Bank), 2022; Alogoskoufis et al. 2021), France (ACPR (Autorité de Contrôle Prudentiel et de Résolution), 2021), the United Kingdom (BoE (Bank of England), 2022), and Japan (FSA and Bank of Japan, 2022) use 30-year-long scenarios.

horizon for scenario analysis is to take into account structural changes in society and the economy, such as the introduction of decarbonization technologies and the transformation of industries and businesses in response to higher carbon prices. In addition, a scenario analysis with a long time horizon makes it possible to examine how those structural changes lead to the reduction of physical risks via a slowdown in global warming. However, considering the transition process in the short run, the carbon price could rise while the business structure is not sufficiently adjusted in response to the carbon price rise. As a result, business conditions and corporate profits could be more adversely affected than if structural changes proceed. In addition, over a long time horizon of about 30 years, credit costs may not uniformly increase throughout the period. In other words, even though the average increase in credit costs during the period may be limited, credit costs may not be negligible during the transitional period when the business structure is not sufficiently adjusted in response to a carbon price rise. For these reasons, it is important to focus on a short time horizon in a scenario analysis.

This paper focuses on the risks in the process of transitioning to a decarbonized society, using a 5-year short-term scenario. By focusing on a short time horizon, we analyze how corporate profits and the transition risks for banks are affected when corporate business or the economy does not sufficiently adjust to a rising carbon price. To conduct the analysis, we explicitly make alternative assumptions regarding the degree to which industries and firms adjust to carbon price increases. Specifically, we assume the following two cases: (1) firms adjust smoothly and (2) firms adjust slowly. We then estimate the impact of these differences in assumptions on the credit cost to banks. Note that physical risk is beyond the scope of the analysis in this paper because the impact of carbon emissions on climate change is expected to be small over a short time horizon of 5 years. In addition, the effects of the introduction of decarbonization technologies to cope with rising carbon prices are not examined.

There have been few short-term analyses for transition risks undertaken by authorities. Exceptions include the Dutch Central Bank's analysis (Vermeulen et al., 2018), which was published before NGFS scenarios became widespread. However, the volatility of energy prices recently showed a sharp increase due to the reduced impact of COVID-19 and the outset of the Ukraine conflict. Against this backdrop, there is a growing interest in considering the risks associated with the transition to a decarbonized society on a short time horizon. For example, in its 2022 scenario analysis, the ECB adopts a 3-year short-term scenario in addition to the typical long-term scenario (ECB, 2022). In addition, the

NGFS also considers developing short-term scenarios (FSB/NGFS, 2022)[5]. As economic and societal efforts to decarbonize become more imminent, in addition to long-term scenarios, short-term scenarios are expected to become increasingly important in order to understand the impacts of the transition process more precisely.

In addition to the argument on the time horizon of scenario analysis, this paper estimates the impact of carbon price increases on industries other than those with large carbon dioxide emissions by using a multi-sectoral general equilibrium model. Many of the previous scenario analyses on climate-related financial risks have focused on "key sectors" that potentially have a large transition risk due to their significant carbon dioxide emissions. However, an increase in the carbon price not only reduces the output of the key sectors, but also can reduce the output of other sectors through inter-industry spillover. The decrease in output by industries for which carbon emissions are not necessarily large could be important for the stability of the financial system, since it would also affect financial institutions that do not have large exposures to the key sectors.

Regarding the two issues mentioned above, the results of our analysis have two implications. First, the degree of firms' adjustment leads to material differences in the degree of deterioration of corporate profits and increase in banks' credit costs. This suggests the importance of taking into account the degree of firms' adjustment to carbon price increases in scenario analysis over a short time horizon. Second, the results show that the carbon price increase not only directly affects the key sectors, but also indirectly spreads to other sectors through inter-industry spillover, and that the credit cost ratios increase in those sectors as well. This suggests that even regional banks with small exposure to the key sectors could be affected by transition risk.

However, the following points should be noted regarding the limitations of our estimates in this paper. First, the assumptions for the two cases regarding the degree to which firms adjust to carbon price increases are very extreme. In the case where firms adjust smoothly, the deterioration of corporate profits is mitigated as excess production capacity and employment are adjusted smoothly in response to the decline in production caused by the rise in carbon prices. However, this could underestimate the increase in the credit cost caused by the downward pressure on the economy because the adjustment costs of employment and capital are not taken into account in the estimates in this paper. On the

[5] In the United States (Federal Reserve Board (FRB), 2023), a bottom-up analysis is conducted based on the NGFS scenarios. The projection period for this analysis is set at 10 years. The use of a medium time horizon is due to two conflicting reasons. On the one hand, analysis with a long time horizon is desirable due to the very nature of climate change. On the other hand, long-term analysis is necessarily subject to large uncertainty in projections, and short-term analysis may be more useful as a material for decision-making and risk management in businesses.

other hand, in the case where firms adjust slowly, even though some firms experience a significant decline in production, they do not adjust their production capacity at all, although this is only for a short period of 5 years. The assumption, therefore, could overestimate the increase in credit costs. Thus, we should not derive quantitative implications from either of the two estimation results, nor should we regard them as tail risks to be considered in risk management in financial institutions; rather, the results are to be interpreted as an example of how the impact of carbon price increases can vary significantly depending on the adjustment pace of firms and the economy as a whole. Future work should include more detailed analysis of the extent to which adjustment costs can arise in the transition to a decarbonized society and take into account the progress of innovations and the pace of transformations of business models.

The second limitation of our results is that, with regard to inter-industry linkages, the magnitude of inter-industry spillovers is also highly dependent on parameters associated with substitutability among factors of production, which are hard to accurately estimate. Therefore, the magnitude of spillovers to sectors other than key sectors and their impact on the cost of credit may be subject to substantial error.

The structure of this paper is as follows. Chapter 2 describes the analysis methodology. Chapter 3 shows the results of the scenario analysis. Chapter 4 discusses future issues.

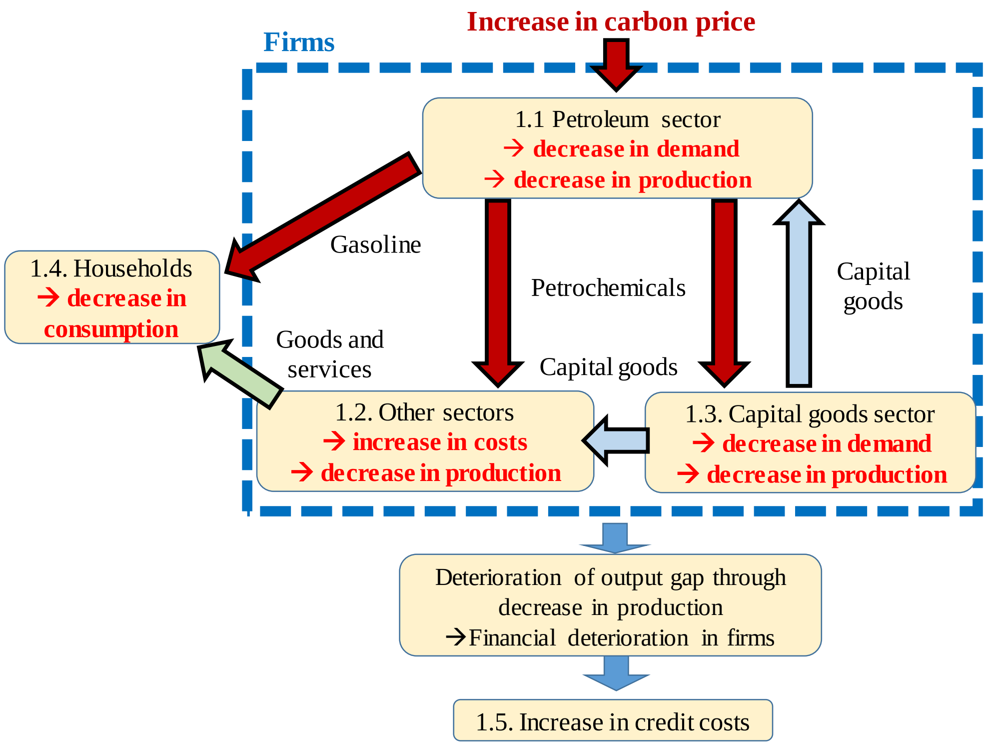
2. Analytical Framework

In the analysis within this paper, we estimate the extent to which an increase in the carbon price changes the credit costs for domestic banks' loans to domestic and foreign corporations. The transmission mechanism of the carbon price increase assumed in our estimation is as follows (Chart 1)[6]. First, an increase in the carbon price raises the price of petroleum and coal products produced by the petroleum and coal product manufacturing industry (Chart 1.1). Higher prices reduce demand for those products, resulting in lower production in the industry. At the same time, production in other industries, such as the electric power industries and steel and other manufacturing industries that use the petroleum and coal products as inputs for production and emit carbon dioxide, declines due to higher production costs (Chart 1.2). The decline in production in a wide range of industries also results in a decline in capital investment. As

[6] The ceramic/soil and stone products and agriculture, forestry, and fisheries industries, which are included in "Other sectors" in Chart 1.2, generate greenhouse gases derived from raw materials other than fossil fuels in the production process, which could lead to an additional increase in production costs as the carbon price rises. Such mechanisms are incorporated into the model in this paper, although they are discarded in Chart 1 for simplicity.

a result, production in the capital goods manufacturing sector decreases due to lower demand for capital goods (Chart 1.3). Household consumption also declines because higher carbon prices increase the prices of gasoline and other goods and services purchased by households (Chart 1.4). Thus, in considering the transmission mechanism of carbon price increases, it is important to take into account the inter-industry linkages. In addition, the output gap worsens significantly, especially if firms in these broad industries are unable to adjust their employment and capital accordingly in response to the decline in their production, resulting in redundant employment and capital. The resulting deterioration in corporate profits leads to higher credit costs for banks (Chart 1.5).

Chart 1. Propagation mechanism of increase in carbon price



Next, Chart 2 summarizes the framework of this paper's analysis. First, the analysis in this paper includes the banks and *shinkin* banks that hold current accounts at the Bank of Japan. By including regional banks with relatively small exposure to key sectors in the analysis, the paper also analyzes the impact on regional banks of spillovers to non-key sectors through inter-industry linkages when carbon prices rise. In addition, the analysis focuses on how corporate profits are affected and credit costs are incurred depending on the pace of adjustment by firms in the transition process toward a decarbonized society. To do the analysis, we adopt a short-term scenario (5 years), as opposed to the long-term scenario (30 years), which tends to presume structural adjustment of firms in response to a carbon price increase. In this regard, we assume two cases with different paces of firms' adjustment to the carbon price increase: (1) a case in which firms adjust their employment and capital quickly in response to the carbon price increase, thereby mitigating the deterioration in profits, and (2) a case in which firms are slow to adjust their employment and capital, resulting in a significant deterioration in profits. Then we evaluate the extent to which the credit cost estimates can differ.

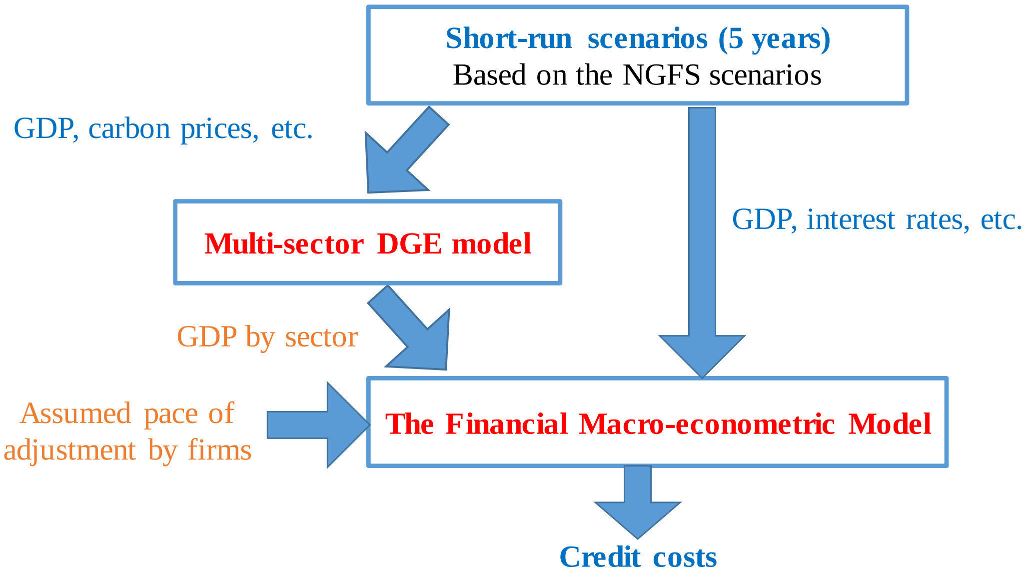
Chart 2. Framework of analysis

	Top-Down analysis (this paper)	(Reference) Bottom-Up analysis of FSA and BOJ (2022)
Coverage	Banks holding current accounts at the BOJ	Three major banks
Scenarios	Based on NGFS scenarios (Ver. 3) (1) Increase scenario (2) Rapid increase scenario (3) Current policies scenario	From NGFS scenarios (Ver. 2) (1) Net Zero 2050 (2) Delayed Transition (3) Current Policies
Simulation period	FY 2022-2026 (5 years)	CY 2021-2050 (30 years)
Firm's adjustment	(1) Smooth adjustment case (2) Slow adjustment case	Arbitrary assumption by each participant

Two points should be noted regarding the assumptions made above on the adjustment pace of firms to an increase in the price of carbon. First, it is possible that an increase in the price of carbon promotes research and development and energy-saving technological progress in firms and society, thereby alleviating the decline in production. However, this paper does not take into account the possibility of such energy-conserving technological progress. In other words, we take as a given the reduction in production due to higher carbon prices and focus on the impact on corporate profits and credit costs of differences in the adjustment pace of firms; namely, how quickly they adjust employment and capital. The second point to note is on adjustment costs. This paper assumes that adjustment costs do not arise when adjusting excess employment and capital, while holding excess employment and capital worsens the output gap, resulting in the fall of corporate profits. In reality, however, when responding to a rise in the carbon price, firms need to pay adjustment costs associated with the impairment loss of the capital asset, which may have a significant impact on corporate profits. While a variety of costs can arise when responding to rising carbon prices, this paper focuses on the costs of holding excess employment and capital.

The analytical framework in this paper combines the following three steps of estimations (Chart 3). First, a multi-sector dynamic general equilibrium model developed by Matsumura et al. (2023) is used to estimate the degree of deterioration in value-added by industry (henceforth, "industry-specific GDP") due to an increase in the carbon price. Second, we estimate the extent to which the decline in industry-specific GDP deteriorates corporate profits in each industry. Third, we estimate the extent to which the deterioration in profits of firms that borrow from banks leads to an increase in the credit cost. For the second and third estimations, we use the Financial Macro-econometric Model (FMM) developed by the Bank of Japan to assess the stability of the financial system.

Chart 3. Flow of analysis



2.1. Concept of Scenarios

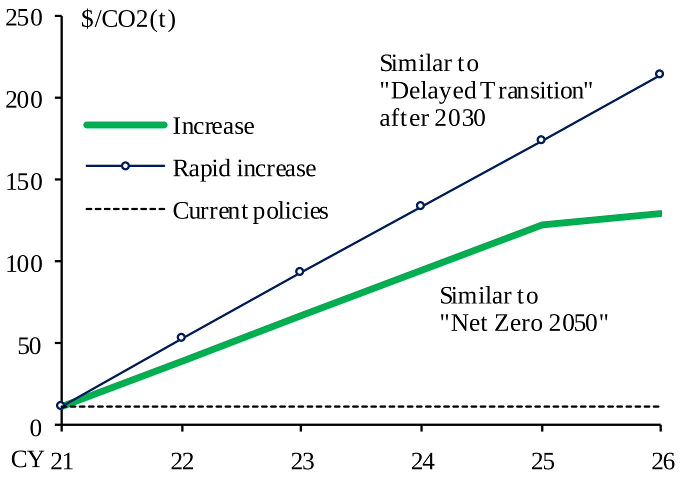
The period of scenarios employed in this paper is 5 years, which is much shorter than typical scenarios employed in the literature, which is around 30 years. We construct three 5-year-long scenarios based on three NGFS scenarios (Phase 3): Net Zero 2050, Delayed Transition, and Current Policies[7].

The specific stress event for the short-term scenario analysis in this paper is a rise in the carbon price. First, as a baseline scenario that assumes no increase in the carbon price, we employ the "current policies scenario," corresponding to the Current Policies in the

[7] See NGFS (2022) for detailed narratives of each scenario.

NGFS. As stress scenarios, we employ two scenarios assuming difference paces of carbon price increases, as shown in Chart 4. The first is the "carbon price increase scenario" (henceforth, the "increase scenario"). This scenario assumes a rise in the carbon price from 2021 at the same rate as in the first 5 years of Net Zero 2050, which aims for net zero global CO2 emissions around 2050. The second stress scenario is the "rapid carbon price increase scenario" (henceforth, the "rapid increase scenario"). This scenario assumes a rapid rise in carbon price from 2021 at the same rate as in the 5-year period after 2030 of Delayed Transition, in which strong emission reduction policies are to be implemented after 2030.

Chart 4. Short-run scenarios for carbon price



Other variables such as country-level GDP, long-term interest rates, and oil prices are also assumed based on the three NGFS scenarios described above[8].

2.2. Calculation of Industry-Specific GDP

Since the impact of a carbon price increase on production can vary greatly depending on the production structure of firms in each industry, we calculate GDP by industry (industry-specific GDP). This calculation is based on a dynamic general equilibrium model by Matsumura et al. (2023) that takes into account the inter-industry linkages. The model incorporates the mechanism whereby changes in firms' intermediate goods input and in capital investment induced by the imposition of a carbon tax spill over to other industries[9].

The first step in calculating industry-specific GDP is to obtain preliminary GDP estimates for an entire country and by industry based on the model by Matsumura et al. (2023)

[8] Appendix A shows the development of scenario variables other than carbon price.
[9] Appendix B shows further explanations of the model.

assuming the carbon price paths obtained by NGFS. Here, while the carbon price is converted to a carbon tax in the model, different tax rates and taxation schemes are applied to each industry when calculating value added by industry. Specifically, the tax rate for each industry is determined based on greenhouse gas (henceforth, "GHG") emissions. As for the taxation scheme, it is assumed that when GHG emissions are due to the combustion of fossil fuels, the tax is levied on the intermediate input of fossil fuels. On the other hand, when GHG is emitted during the production process, as is the case for the production of cement products, the tax is levied on sales of the product. We also assume that external factors other than the carbon price remain constant throughout the simulation period. The preliminary GDP estimates by industry thus calculated are adjusted so that the GDP of an entire country is consistent with the corresponding NGFS scenarios. The same method is applied to both domestic and foreign industry-specific GDP.

Charts 5 and 6 show domestic and foreign industry-specific GDP, respectively, calculated using the above methods. The carbon price increase substantially raises the prices of petroleum and coal products. The petroleum and coal product industry thus faces a large decrease in demand, resulting in a significant decrease in its value-added. At the same time, the industries that emit GHG in the production process, such as the ceramic and stone products, agriculture, forestry and fisheries, and gas and water industries, also experience a significant decrease in their value-added as a result of increased production costs due to higher carbon prices. In addition, because these industries face a large and permanent reduction in demand into the future, they substantially reduce capital investment. As a result, the value-added of general machinery significantly declines due to the reduced demand for capital goods. This mechanism of inter-industry linkages through capital investment is a unique contribution of this paper that has not been captured in previous studies, such as Devulder and Lisack (2020) and Frankovic (2022).

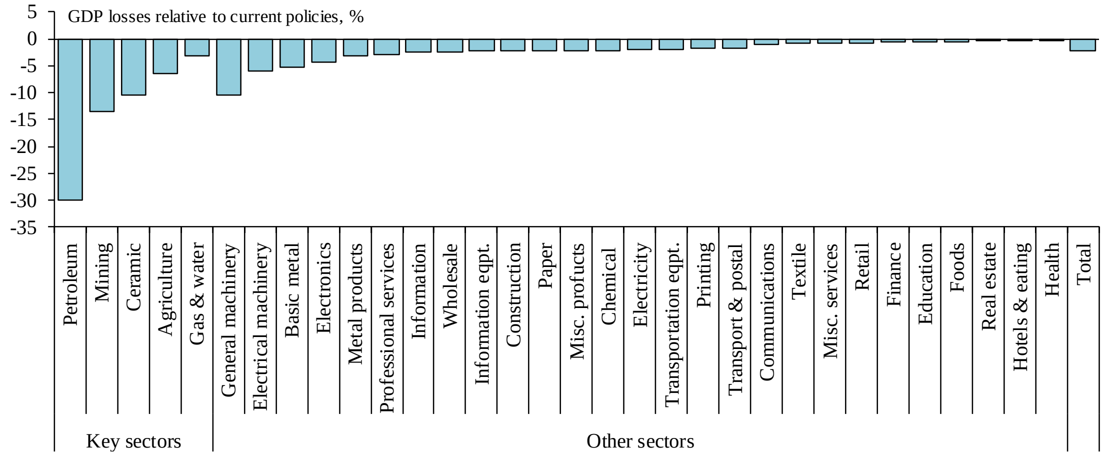
2.3. Degree of Adjustment to Carbon Price Increase and its Impact on Corporate Profits

Next, we calculate financial variables of corporates in each industry using the industry-specific GDP calculated above. Here, we convert GDP into deviations from the trend, or output gap, and calculate their impact on corporate financial variables such as ROA and interest coverage ratio (ICR)[10].

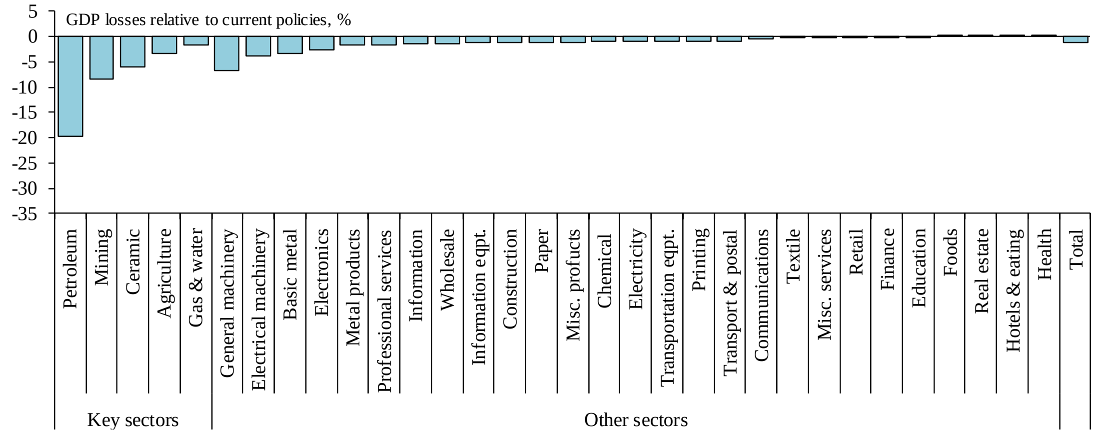
[10] The reason why we use deviations from the trend rather than the level of GDP itself is that, unlike the level of GDP, which has a clear increasing trend, the explained variables of our interest -- namely, the financial variables of corporates such as ROA -- do not have an obvious long-term trend.

Chart 5. Domestic industry-specific GDP (average of simulation period)

Rapid increase



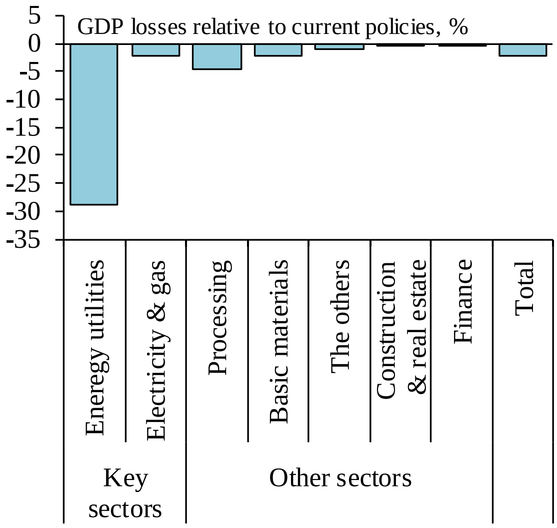
Increase



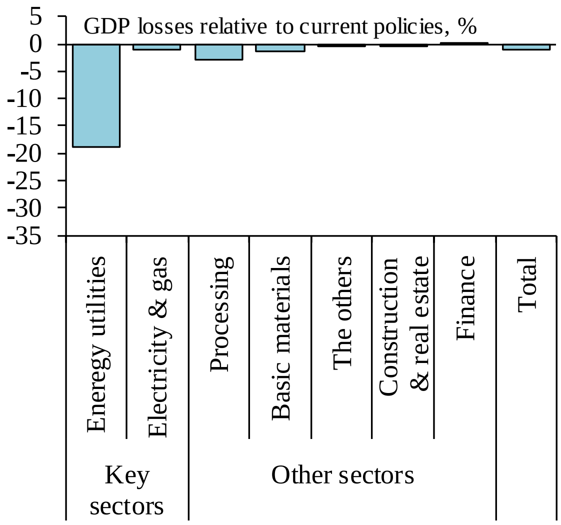
Note: "Petroleum" refers to "Petroleum and coal products manufacturing sector."

Chart 6. Foreign industry-specific GDP (average of simulation period)

Rapid increase



Increase



The GDP trend used to calculate the output gap can be interpreted as supply capacity in terms of production facilities and employment in each industry. After a time horizon as long as 30 years, the GDP trend is likely to significantly change as production facilities and employment are adjusted to the decline in output associated with higher carbon prices. However, if we consider a short time horizon, it is conceivable that the adjustment of production facilities and employment is not sufficient and the GDP trend does not significantly change. Based on these considerations, we adopt the following two cases in this short-term scenario analysis.

The first is a case in which production facilities and employment are adjusted relatively quickly to the fall in GDP due to a rise in carbon prices, and this is referred to as the "smooth adjustment case." In this case, in both the "increase scenario" and the "rapid increase scenario," we assume that after a certain period, the adjustment of production facilities and employment to the fall in GDP is completed. As shown in Chart 7, the GDP trend therefore catches up with the fall in GDP, and the output gap does not become too bad[11]. In this case, the deterioration in corporate profits is alleviated and the impact on banks is relatively contained.

The second case is one in which firms are slow to adjust the number of employees and facilities despite the decline in GDP, and this is referred to as the "slow adjustment case." In this case, we assume that even if some industries experience a large decline in GDP due to a carbon price increase, they do not accordingly adjust production facilities and employment. As shown in Chart 8, the GDP trend therefore does not decline, resulting in a deeply negative output gap[12]. In this case, corporate profits significantly deteriorate, and the impact on banks is also large.

Both the "smooth adjustment case" and the "slow adjustment case" assume unlikely situations for simplicity. On the one hand, in the "smooth adjustment case," the deterioration in corporate profits is relatively limited. However, this is partly due to a simplifying assumption that the cost of adjusting employment and production facilities in relation to the decrease in production caused by the carbon price hike is negligible. On the other hand, the "slow adjustment case" also assumes an extreme situation in which firms facing a significant decline in output do not adjust their production capacity at all, although this is for a short period of 5 years. By assuming the two extreme cases, the

[11] In this case, the GDP trend is estimated by applying a one-sided Hodrick-Prescott (HP) filter to the industry-by-industry GDP that declines due to higher carbon prices.

[12] In this case, the trend is estimated by applying a one-sided HP filter to GDP by industry under the "current policies scenario," in which carbon prices do not rise and GDP does not show any material decline.

analysis in this paper focuses on understanding the extent to which differences in firms' adjustment pace influence the credit cost ratios for banks.

Chart 7. Output gap (smooth adjustment)

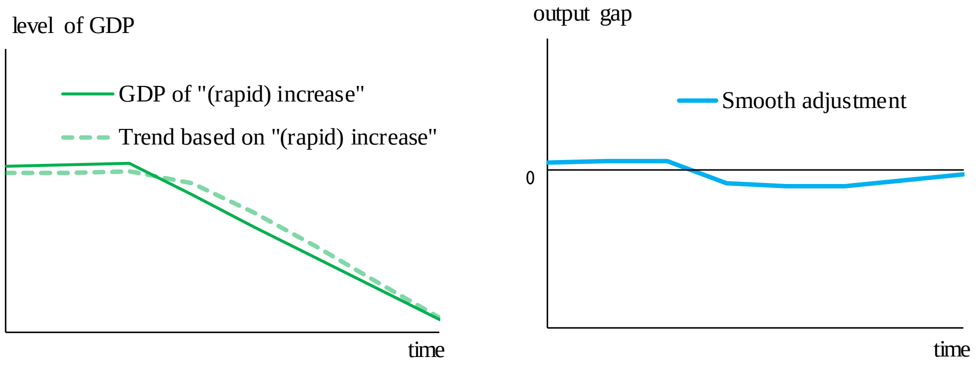
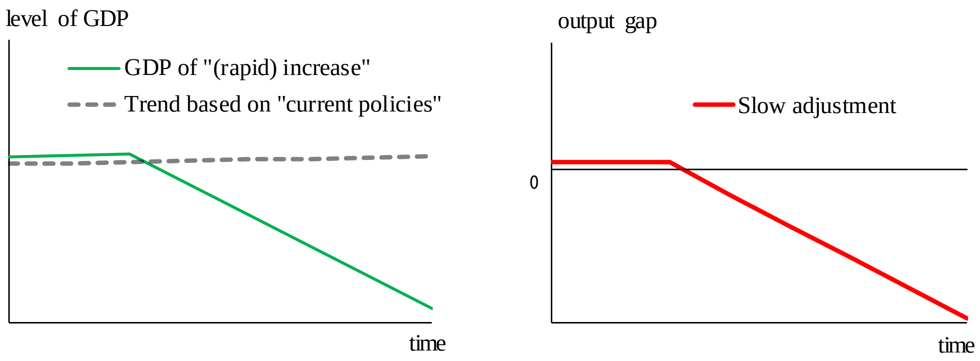


Chart 8. Output gap (slow adjustment)



2.4. Calculation of Credit Costs

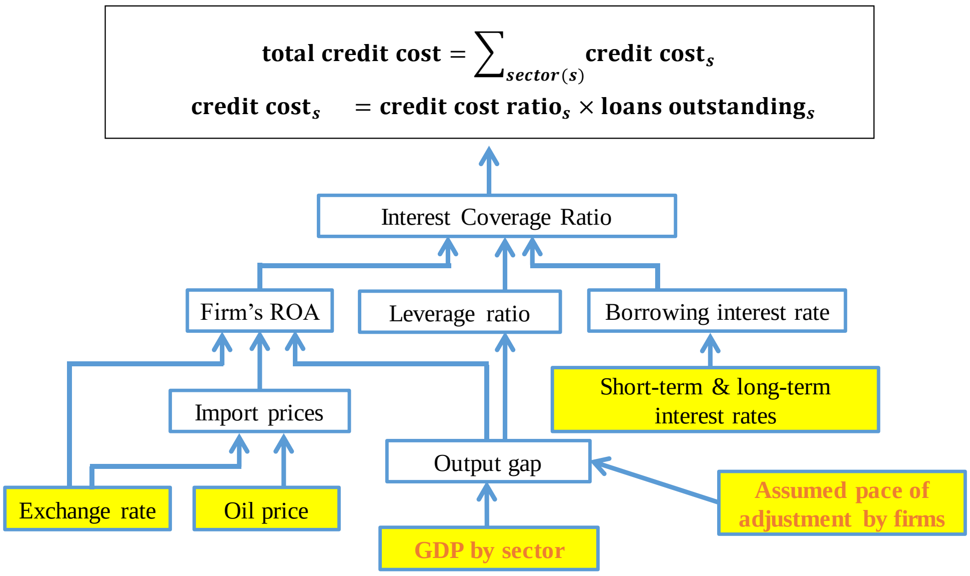
Next, we estimate the credit cost ratio by industry based on the industry-by-industry output gap[13]. The credit cost ratio is a function of financial variables of corporates, and the financial variables in turn are functions of macroeconomic variables such as the output gap. To calculate the credit cost ratio for a bank, the credit cost ratios of all industries estimated above are averaged using the industry composition of loans extended by the bank as weight.

Here we describe estimation of the credit cost ratio by industry in more detail. The ICR, an important financial variable in determining the domestic credit cost ratio in FMM, is composed of (a) ROA, (b) the leverage ratio, and (c) the borrowing interest rate, as illustrated in Chart 9. By factor, (a) ROA is a function of the exchange rate (dollar/yen),

[13] See Abe et al. (2023) for details on the estimation method of credit cost ratio.

import prices, and the output gap. The appreciation of the exchange rate, the rise in import prices, or the worsening of the output gap leads to the deterioration of ROA. While the elasticity of ROA to these macro variables is assumed to be common across industries, the extent to which ROA deteriorates due to higher carbon prices and the resulting increase in the credit cost ratio differs by industry because of the heterogeneity in the output gap. Meanwhile, (b) the leverage ratio increases as the output gap worsens, and (c) the borrowing rate increases as the long- and short-term interest rates rise. Based on these financial variables, we calculate credit cost ratios by industry. While the credit cost ratios of foreign loans are estimated in a somewhat simpler way than those of the domestic loans described above, similarly to the domestic credit cost ratios, the foreign credit cost ratios take into account factors such as the output gap and the borrowing interest rates.

Chart 9. Transmission path of credit costs in FMM



Note: Highlighted variables in yellow are exogenous.

Lastly, we calculate the credit cost ratio for a bank by taking the weighted average of the domestic and foreign industry-by-industry credit cost ratios using the industry composition of loans extended by the bank as weight. For the weight, we use the actual values of loans outstanding as of the end of March 2022 throughout the simulation period. This so-called "static balance sheet assumption" is used in many transition risk analyses conducted in other jurisdictions. If banks actively change the industry composition of their balance sheets in light of rising carbon prices, they would likely reduce their exposure to industries such as petroleum and coal products, for which GDP substantially shrinks due to higher carbon prices. The simulations in this paper, which do not incorporate such active portfolio changes, are conservative estimates in the sense that they likely overestimate resulting credit cost ratios.

3. Results

This chapter presents the credit cost ratios estimated in line with the methodology described in Chapter 2. Section 3.1 describes the credit cost ratios by industry, and Section 3.2 describes those by type of banks.

3.1. Credit Cost Ratios by Industry

As explained in Section 2.4, we calculate the credit cost ratio faced by each bank by taking weighted averages of domestic and foreign industry-by-industry credit cost ratios using the industry composition of the loans extended by the bank as weight. This section describes the results of the domestic and foreign credit cost ratios by industry.

Charts 10 and 11 show the estimates of industry-by-industry cumulative credit cost ratios over the analysis period (5 years) under the "slow adjustment case" (see Section 2.3) for domestic and foreign loans, respectively. The upper panel (left panel) of Chart 10 (Chart 11) shows the difference in credit cost ratios of the "rapid increase scenario" from the "current policies scenario," while the lower panel (right panel) shows that of the "increase scenario." The following three characteristics can be pointed out from these charts. First, in both the "rapid increase scenario" and the "increase scenario," relatively large credit costs are incurred in key sectors, such as the domestic petroleum and coal products manufacturing sector and the foreign energy sector. This is consistent with analyses of transition risk conducted in other jurisdictions. Second, somewhat large credit costs are also incurred in some of the other sectors, especially those producing capital goods, such as the domestic general machinery manufacturing sector. This is due to the mechanism whereby, as described earlier, the decline in capital investment of the key sectors, including petroleum and coal product manufacturing, due to their lower GDP depresses demand for capital goods. Third, the credit cost ratio of all industries for the "rapid increase scenario" is larger than that for the "increase scenario"[14]. These three characteristics are consistent with the characteristics in industry-specific GDP in Section 2.2, as shown in Charts 5 and 6[15].

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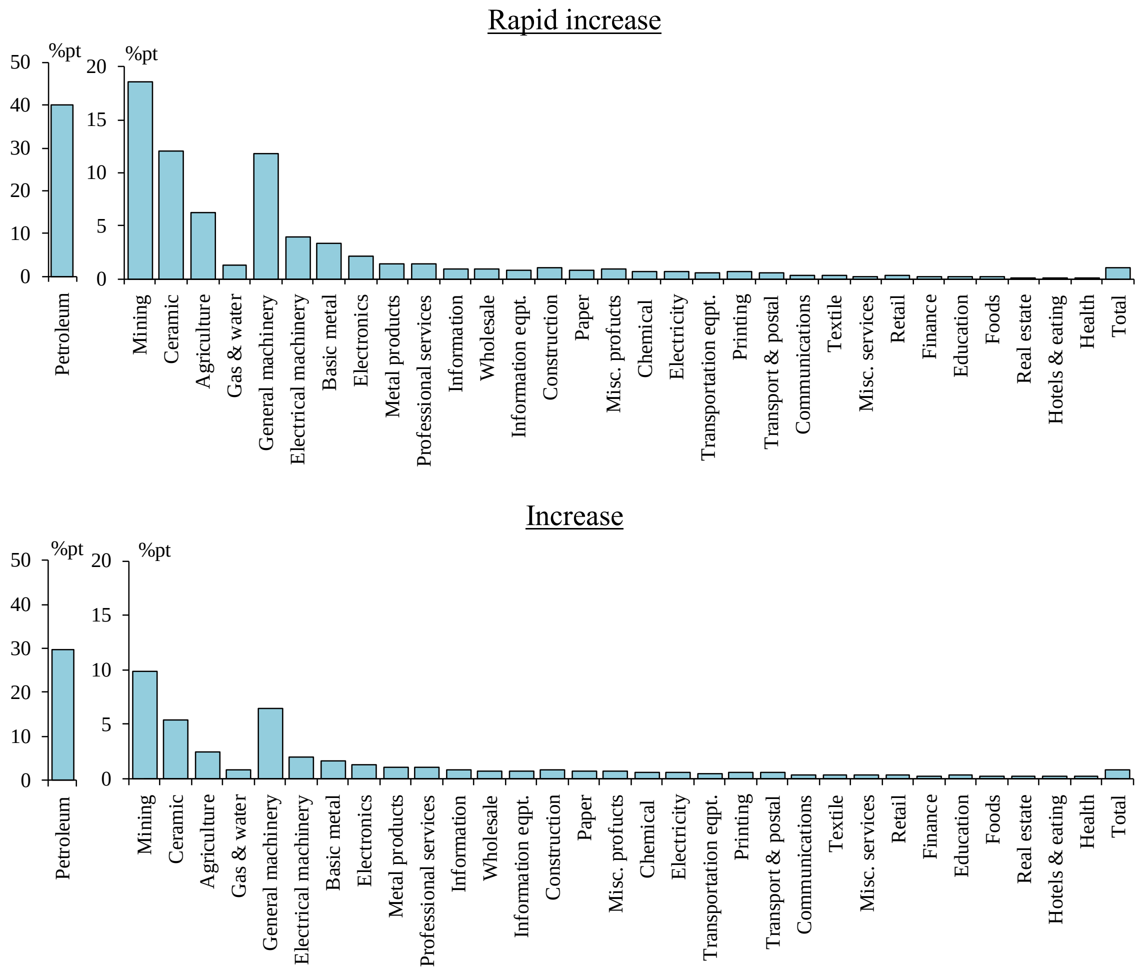
[14] The credit cost ratio of all industries is calculated based on the average of the industry composition of loans extended by all banks.

[15] Another characteristic in Chart 10 is that the credit cost ratios in the "increase scenario" are larger than those in the "rapid increase scenario" for industries such as health services and hotels and eating, which are not affected much by transition risk and are therefore located on the right-most side of the chart. This is due to the effect of relatively higher long- and short-term interest rates in the "increase scenario," which push up borrowing interest rates for corporates, putting downward pressure on the ICR.

Chart 10. Domestic credit cost ratios by sector under slow adjustment
(Cumulative value, relative to current policies)



Note: "Petroleum" refers to "Petroleum and coal products manufacturing sector."

Chart 11. Foreign credit cost ratios by sector under slow adjustment
(Cumulative value, relative to current policies)

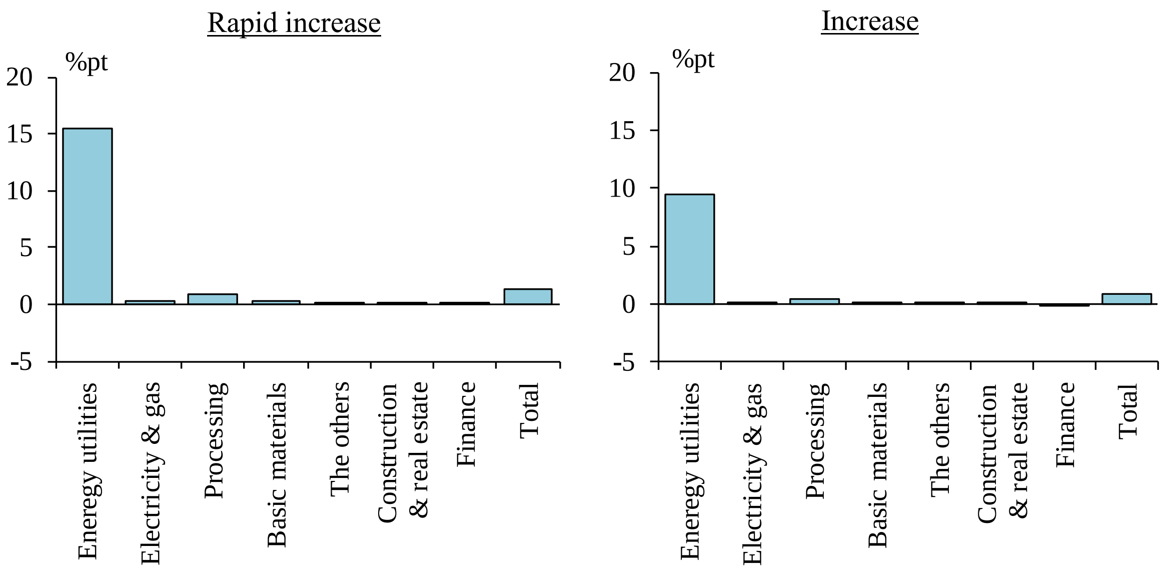
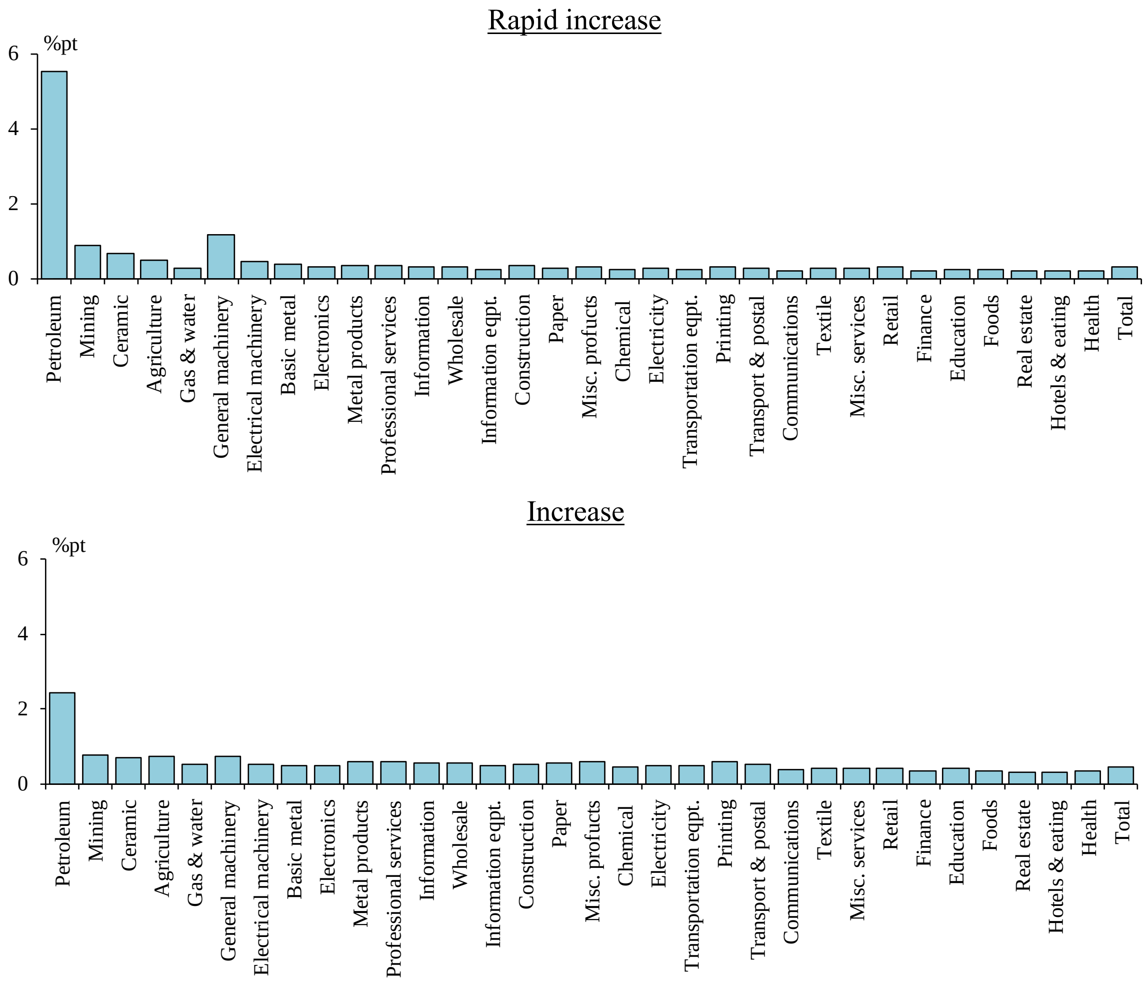
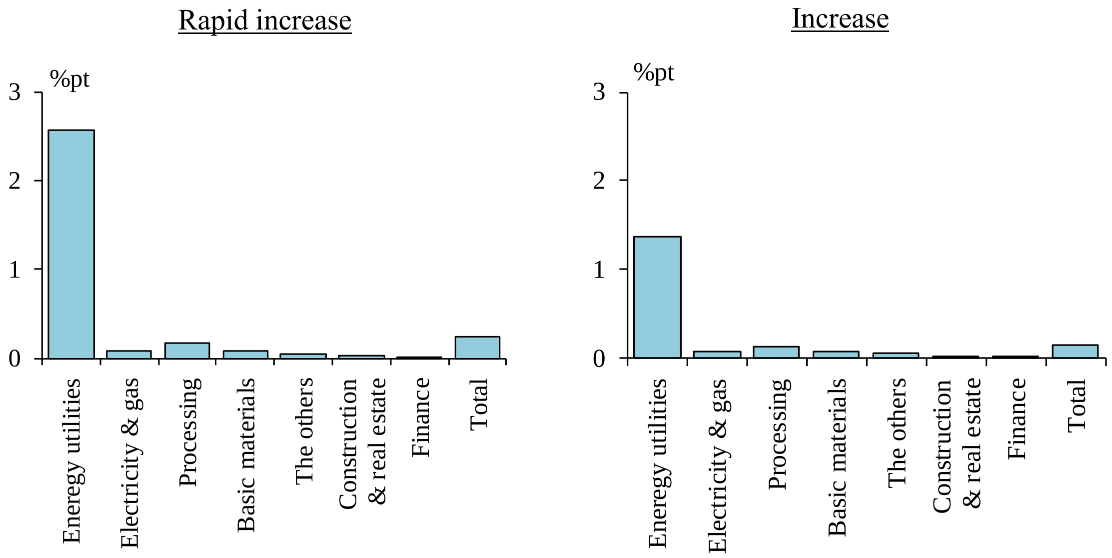


Chart 12. Domestic credit cost ratios by sector under smooth adjustment
(Cumulative value, relative to current policies)



Note: "Petroleum" refers to "Petroleum and coal products manufacturing sector."

Chart 13. Foreign credit cost ratios by sector under smooth adjustment
(Cumulative value, relative to current policies)



Charts 12 and 13 show the estimates of industry-by-industry cumulative credit cost ratios over the analysis period (5 years) under the "smooth adjustment case" for domestic and foreign loans, respectively. The upper panel (left panel) of Chart 12 (Chart 13) shows the difference in the credit cost ratios of the "rapid increase scenario" from the "current policies scenario," while the lower panel (right panel) shows that of the "increase scenario." Compared to the "slow adjustment case" shown above, the deterioration in credit costs is smaller, especially in the key sectors and the industries related to capital goods, where the decline in industry-specific GDP is larger.

As mentioned earlier, the credit costs are larger for "slow adjustment case". However, this case assumes a rather extreme situation that does not take into account any reaction by corporates to the carbon price increase during the simulation period. Therefore, rather than considering this case as a tail risk that should be taken into account in risk management, it should be understood as an example of how the impact of carbon price increase can vary greatly depending on the pace of adjustment by corporates and the economy as a whole.

3.2. Credit Cost Ratios by Type of Banks

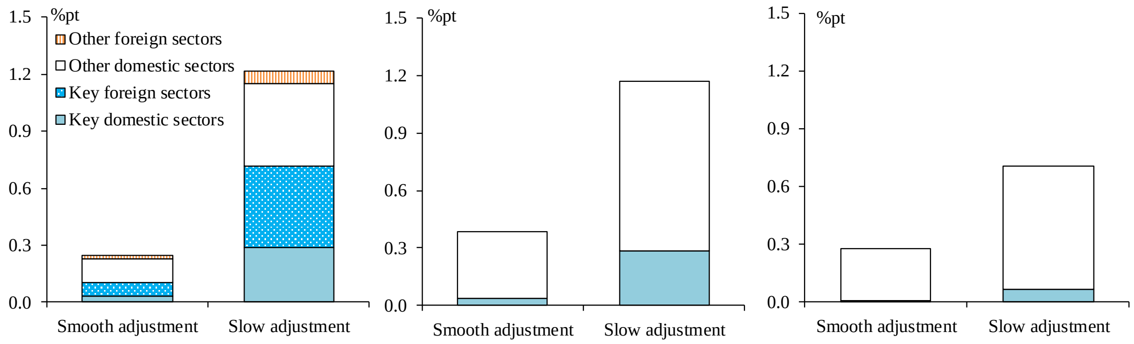
The credit cost ratio faced by each bank is estimated by taking the weighted average of credit cost ratios by industry described in the previous section using the industry composition of loans extended by the bank as weight. Chart 14 shows the credit cost ratios for the "smooth adjustment case" and the "slow adjustment case" by type of banks; namely, internationally active banks, domestic banks excluding *shinkin* banks, and domestic *shinkin* banks. The upper panel shows the results for the "rapid increase scenario," while the lower panel shows the results for the "increase scenario."

We observe the following three points from this chart. First, as is consistent with the results by industry shown in the previous section, the estimated credit cost ratios are largest in the "slow adjustment case" under the "rapid increase scenario" for all types of banks. Second, for the internationally active banks, the loans to foreign energy sector substantially contribute to the worsening of credit cost ratios, especially in the "slow adjustment case," given their relatively large exposure to that sector. Third, for domestic banks, which do not have significant exposure to domestic key sectors, the loans to other sectors, especially those related to capital goods, make a substantial contribution to the credit cost.

Chart 14. Credit cost ratios by banks (Cumulative value, relative to current policies)

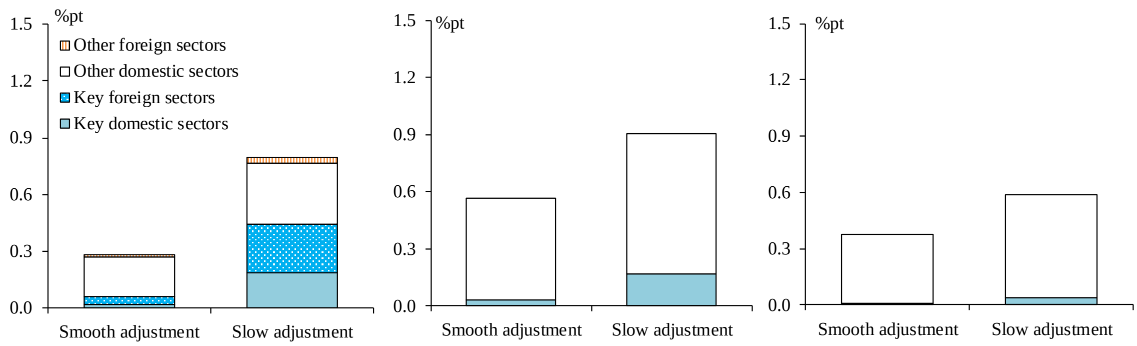
Rapid increase

Internationally active banks | Domestic banks (excl. *shinkin*) | Domestic *shinkin* banks



Increase

Internationally active banks | Domestic banks (excl. *shinkin*) | Domestic *shinkin* banks



The third point highlights a unique feature of our analysis. Many scenario analyses for transition risk conducted in other jurisdictions, including ECB (2022), the Bank of Canada (BoC) and the Office of the Superintendent of Financial Institutions (OSFI) (2022), as well as the Financial Services Agency (FSA) and the Bank of Japan (BoJ) (2022), primarily focus on the key sectors that are directly affected by carbon price increase. The analysis in this paper also shows that the deterioration in the credit cost ratios for the key sectors is larger than for most of the other sectors. However, especially for domestic banks, the other sectors make larger contributions to total credit cost because of the larger share of those sectors in domestic banks' loan portfolios. This suggests that even regional banks with relatively small exposure to key sectors need to pay close attention to the transmission of transition risk through inter-industry spillovers.

4. Conclusion

This paper presents a top-down scenario analysis of transition risk for banks. In the analysis, we shorten the time horizon to 5 years and make two different assumptions regarding the adjustment pace of firms to a carbon price increase, in order to take into account the impact of different degrees of adjustment during the transition process. In addition, we use a multi-sector dynamic general equilibrium model to analyze the impact of inter-industry spillovers, taking into account inter-industry linkages. The results of the analysis are as follows. First, we find that differences in the adjustment pace of firms to a carbon price increase can cause a substantial difference in a bank's credit cost ratio in the short-term scenario analysis. Second, a carbon price increase affects not only the key sectors directly affected by that, but also other sectors through inter-industry linkages. As a result, our estimates show that even regional banks with relatively small exposure to the key sectors suffer from an increase in their credit cost ratios.

These estimation results suggest the following points. First, differences in assumptions about the adjustment pace of firms have a significant impact on the credit cost ratio, which indicates the importance of analyzing transition risk scenarios over a short time horizon, where firms may not be able to adjust sufficiently. This also suggests that assumptions regarding the adjustment pace of firms are crucial. Second, while the analysis of transition risk often focuses on the key sectors, even regional banks with relatively small exposure to the key sectors need to be aware of transition risk due to indirect spillover effects.

While this paper focuses on the impact of an increase in the carbon price, the framework of this analysis may be applicable to the analysis of transition risk caused by other factors. For example, one possible scenario is that a wide range of economic agents, including households and firms, begin to avoid the goods and services of industries that emit large amounts of GHG, and that transition risks emerge through reduced demand for those industries. This scenario is not explicitly included in the scope of analysis in this paper. However, the analytical framework in this paper may be useful in analyzing the scenario. Namely, the analysis in this paper includes a mechanism whereby production in industries that emit large amounts of GHG declines, pushing down demand for capital goods through inter-industry linkages. Even under the scenario of agents avoiding "brown" products, the inter-industry linkages and the resultant decrease in demand for capital goods may matter. In addition, credit costs may change correspondingly depending on the adjustment pace of firms to such changes in demand.

Lastly, we present three remaining issues to be addressed in future research. The first issue is about assumptions on the adjustment pace of firms. The results of the analysis indicate that the adjustment pace affects the credit cost ratio estimates. However, since this analysis relies on a simplified assumption on the adjustment pace of firms, we should notice that the quantitative results of the simulation are subject to vary depending on assumptions. In order to make estimates more useful, the remaining issues to be addressed include the pace at which new production technologies and business models are established to realize a decarbonized society, and the required level of investment for that to happen[16]. It is necessary to collect data and information to make more concrete assumptions on these issues and to build a model that incorporates such assumptions.

The second point concerns adjustment costs for capital assets. This paper assumes that a carbon price increase leads to a negative output gap, thus deteriorating corporate profits. In reality, when the carbon price rises, adjustment costs for capital stock may also arise, which worsen corporate profits. As a future issue, it is necessary to build a model that takes into account the adjustment costs associated with the impairment loss of facilities and equipment of firms that emit large amounts of GHG during the transition to a decarbonized society. In addition, we have to collect data to estimate such adjustment costs.

Third, an international consensus for the short-term scenario has not yet been established. How to set up short-term scenarios and their relationship with long-term scenarios is also related to the issue of what assumptions should be made in the transition process to a decarbonized society, as mentioned earlier. In addition to the development and use of dynamic models for analyzing the transition process, it is necessary to develop a conceptual understanding of the time frames for both short-term and long-term analyses.

[16] For the relationship between various policy instruments and technological innovations for climate change, see Acemoglu et al. (2012) and others.

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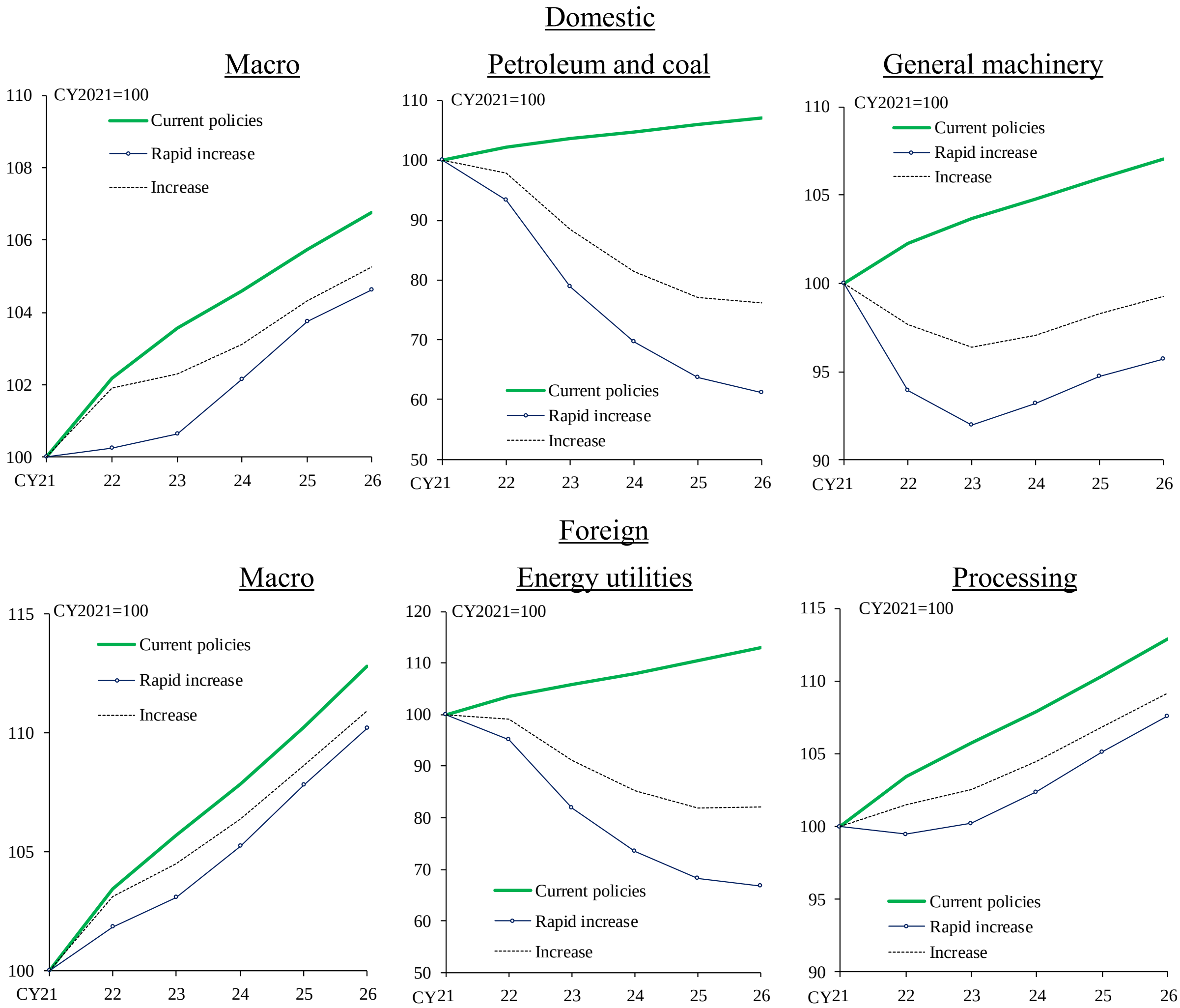
Appendix A: Scenario Variables

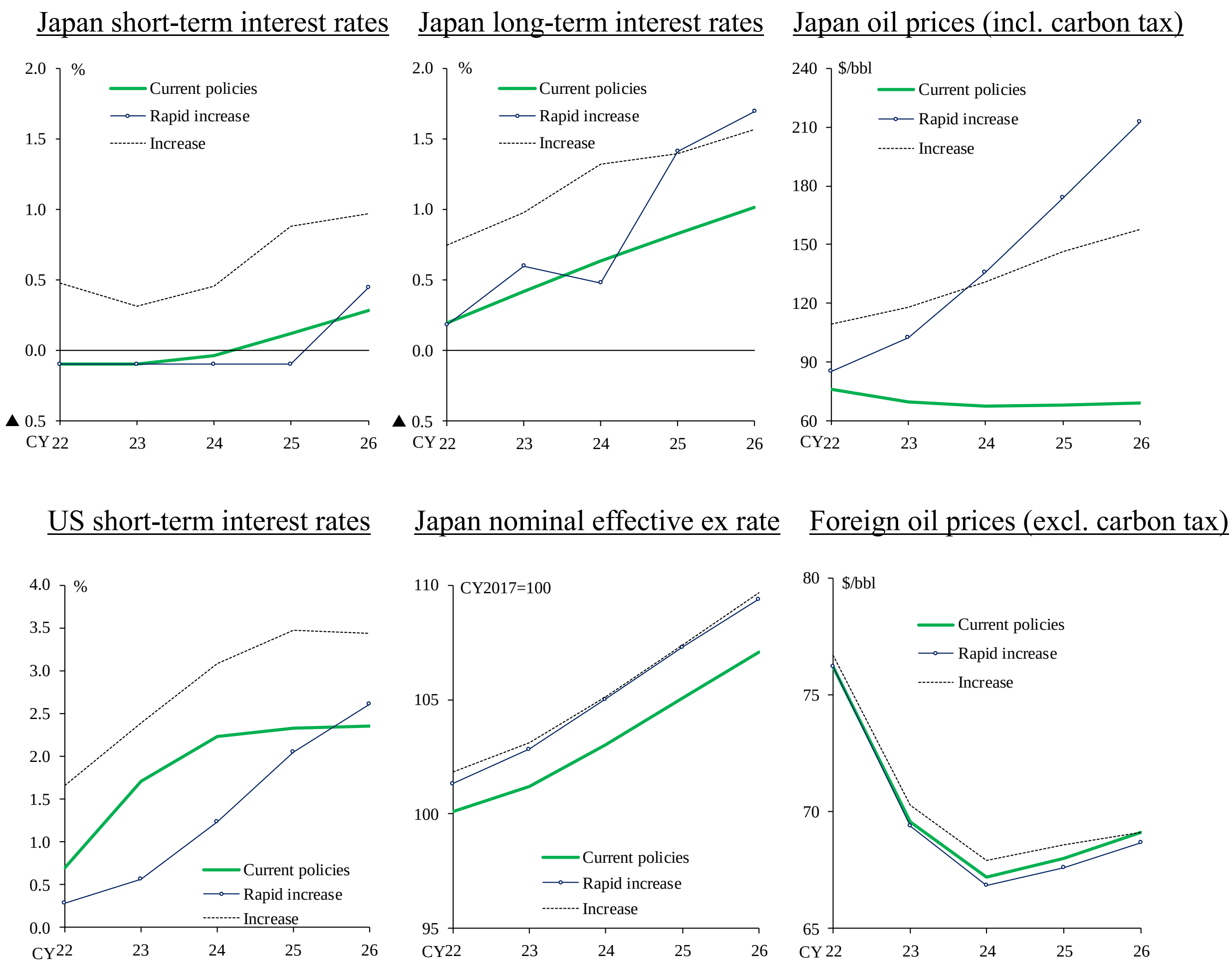
Appendix A explains the main scenario variables used in the analysis. We set paths of GDP for the increase scenario, the rapid increase scenario, and the current policies scenario based on the GDP scenarios of Net Zero 2050, Delayed Transition, and Current Policies for Japan in the Phase III NGFS scenarios, respectively. Subsequently, based on the path of GDP, we calculated the path of industry-specific GDP using the method described in Section 2.2. As depicted in Charts 5 and 6, for many industries, the GDP under the increase scenario and the rapid increase scenario is lower than that under the current policies scenario. The decline in industry-specific GDP is particularly pronounced for the petroleum and coal products industry, which is most directly affected by rising carbon prices, and for the ceramic products industry, which emits large amounts of GHG in the production process. In addition, the general machinery industry, which produces capital goods, faces a decline in GDP due to lower capital investment (Appendix Chart 1).

Appendix Chart 1. GDP



Domestic and foreign interest rates rise in the increase scenario, reflecting higher carbon prices, while they decline in the rapid rise scenario due to economic deterioration (Appendix Chart 2). Domestic crude oil prices (including carbon tax) rise sharply in response to higher carbon prices, which exerts downward pressure on domestic corporate profits. On the other hand, foreign crude oil prices (excluding carbon tax) declines in response to lower demand, leading to decreased profits for foreign energy industries.

Appendix Chart 2. Interest rate, exchange rate and oil prices



Appendix B: Overview of a Dynamic General Equilibrium Model Incorporating Inter-Industry Linkages

The impact of the rise in carbon prices on corporate creditworthiness varies widely across industries. While the NGFS provides a wide range of variables for different climate scenarios, as of Phase III, only a limited number of industry-specific variables are available. To address this gap, scenario analyses conducted by other central banks, such as Allen et al. (2020) and ECB/ESRB (2022), rely on the results of general equilibrium models that incorporate inter-industry (sectoral) linkages (e.g., Devulder and Lisack (2020), Frankovic (2022)).

In this paper, we have developed paths of industry-specific scenario variables based on Matsumura et al. (2023). In contrast to Devulder and Lisack (2020) and Frankovic (2022), Matsumura et al. (2023) focuses exclusively on the Japanese economy and abstracts from international trade. However, it is a dynamic model that incorporates capital investment. The model also captures spillover effects through firms' forward-looking capital investment behavior. This Appendix provides an intuitive overview of the model. A comprehensive description of the model, including mathematical formulations, is presented in Matsumura et al. (2023).

The model in Matsumura et al. (2023) is a dynamic general equilibrium model that incorporates sectoral linkages. Furthermore, it shares the same structure as standard models used for analyzing business cycles, including adjustment costs of capital stock and price rigidities. The model comprises 32 industries, each of which produces goods while utilizing goods produced by other industries as intermediate inputs. For instance, if a carbon tax is imposed on the use of fossil fuels, a major source of carbon emissions, the fossil fuel sector experiences a substantial decrease in demand. This is because each industry substitutes intermediate inputs for alternative goods, leading to a significant reduction in value-added. Additionally, sectors heavily reliant on fossil fuels would encounter a notable increase in production costs, resulting in higher selling prices and reduced production.

In addition, capital goods are essential inputs for production. Many industries, for instance, rely on general machinery products for their capital investments. The imposition of a carbon tax on the use of fossil fuels is anticipated to lead to a substantial decrease in future demand for the petroleum and coal industry. Consequently, this reduction in demand will result in a significant decline in capital investments, subsequently leading to a reduction in the production of general machinery.

In this model, the increase in the carbon price is translated into a carbon tax increase. Specifically, we assume three types of carbon taxes based on GHG emissions: 1. At the intermediate input stage, a carbon tax is imposed on GHG emissions resulting from energy combustion. In other words, when energy (e.g., petroleum and coal products) is used as an intermediate good, a tax is levied on the purchase of energy. 2. At the production stage, the tax is imposed on GHG emissions that do not involve energy combustion. For example, GHG emissions occur from the combustion of limestone in the production of cement. In this case, the tax is applied to the production (i.e., sales) of cement. 3. At the final consumption stage, a carbon tax is levied on GHG emissions resulting from households' consumption activities. For instance, since households emit CO2 by driving a car powered by gasoline, the tax is applied to household gasoline purchases. Given that the majority of GHG emissions from households originate from petroleum and coal products, including gasoline, this analysis assumes that only the consumption of petroleum and coal products is subject to taxation.

We calibrate the parameters of the model using the 2015 input-output table. We estimate an industry-specific GDP path consistent with the carbon price provided in the NGFS scenario. The model shows that the petroleum and coal industry, which faces declining demand, sees a particularly large decline in sectoral value-added, and the ceramic products industry, which emits a large amount of GHG in its production stage, also faces a relatively large decline in sectoral value-added. The value-added of general machinery declines due to lower capital investment demand, mainly from the petroleum and coal industries. While the outlook for industry-specific GDP can be affected by a variety of factors, including technological innovation and changes in consumer preferences, in this estimation we have limited our analysis to the impact of higher carbon prices. Note that the results depend on assumptions about specification of production and utility functions in the model.