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ASSESSING THE FINANCIAL IMPACTS OF CLIMATE-RELATED RISKS ON HONG KONG-LISTED NON-FINANCIAL FIRMS: A FORWARD-LOOKING ANALYSIS BASED ON NGFS SCENARIOS

Key points:

- *Climate change is one of the most pressing challenges facing the world today. In particular, the transition towards a low-carbon economy will inevitably affect many economies and sectors on various fronts, potentially posing significant long-term implications for financial stability. This points to the growing importance of strengthening climate risk assessment and monitoring framework globally.*

- *To strengthen our systemic risk analysis on climate-related issues, this study develops a top-down analytical framework to assess the financial impacts of climate-related risks on non-financial corporates listed in Hong Kong over a 30-year horizon based on various reference climate-transition scenarios by the Network of Central Banks and Supervisors for Greening the Financial System (NGFS).*

- *Overall, our analysis suggests that the credit risks arising from climate-related risks should be relatively manageable for most of the firms in Hong Kong across different scenarios, as the vast majority of firms listed in Hong Kong are not from emission-intensive sectors and thus less subject to high transition risks.*

- *However, some firms, especially from emission-intensive sectors, could face material transition risks and therefore may be subject to a notable rise in credit risks under the "disorderly transition" scenario.*

- *Another key finding is that the longer-term impacts of climate transition risks on firms' default risks will be significantly smaller in the "orderly transition" scenarios than in the "disorderly transition" scenario. In addition, the impact of physical risks under these transition scenarios is found to be lower than "no action" case. These results together support the notion that there are clear benefits in taking climate actions, and acting early.*

- *Nevertheless, cautions should be exercised when interpreting the results as there are some caveats in the analysis, such as data gap issues and large uncertainties in estimates for a long time horizon. Given the growing importance in strengthening climate risk assessment, more research efforts in addressing these caveats are highly warranted going forward.*

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1. INTRODUCTION

Climate change is undoubtedly one of the most pressing challenges facing the world today and has become a core part of the agenda of public and private sectors globally. The transition towards a low-carbon economy will inevitably affect many countries and sectors on various fronts. For instance, changes in climate policies, and the adoption of climate-related technology designed to reduce greenhouse gas emissions (GHG), may have significant financial implications for a wide range of industries. Indeed, future business operations of firms could be structurally affected and undermine their financial soundness (i.e. transition risk). Conversely, firms may suffer direct damage to their physical assets or disruption to their business operations stemming from catastrophic climate events (such as floods or storms), and chronic physical risks (such as rising sea levels or heat waves) if insufficient action is undertaken by countries in limiting the rise in global temperature (i.e. physical risk). **In view of the multifaceted impacts of climate-related risks, there is a growing emphasis on firms, financial institutions and regulators to strengthen their climate risk management and monitoring framework globally.**

In practice, however, it is challenging to assess the effects of climate-related risks over a long time horizon for two reasons. First, climate-related risks are the products of multiple interacting forces (e.g. natural, technological and societal) which span over a long time horizon. The associated effects are thus inherently uncertain and prone to changes. Second, historical data may not be sufficient or is simply non-existent for analysis due to the fact that certain types of climate-related risks (such as transition risk) have no precedent for many countries. And, for physical risk, even if past data are available, they may not be reliable in extrapolating the future impacts of physical risk given that weather conditions are becoming more extreme, and past weather patterns may have been structurally changed. **As such, the lack of consistent analytical frameworks and forward-looking data have been a major hurdle for central banks and others to conduct a climate risk assessment.**

To facilitate the development of such a framework for central banks and regulators, the Network of Greening the Financial System (NGFS), together with an expert group of climate scientists and economists, have contributed by developing and publishing a granular database of different reference climate scenarios for a wide range of countries, and also covers an extensive lists of indicators. Each scenario represents a joint path of economic growth, GHG emissions, energy prices and other key indicators over a long period of time, which enable users to explore the transition and physical impacts of climate change in a coherent framework. **The NGFS climate scenarios, therefore, provide a common reference point that facilitate central**

banks and supervisors to evaluate the effects of climate change on a consistent and comparable basis. Indeed, the NGFS scenarios have been increasingly employed by many central banks in their climate risk assessment and climate stress testing framework (Alogoskoufis et al, 2021). The HKMA has also recently conducted and published the results of the first pilot climate risk stress test exercise (CRST) on the Hong Kong banking sector, which used the NFGS scenarios as important inputs for the assessment of the transition risk.[1]

Building on the contribution of the NGFS and related analysis by major central banks, this study attempts to develop a forward-looking analytical framework to assess the financial impacts of the associated climate-related risks on corporates in Hong Kong. In particular, the analysis focuses on the impacts of the transition and physical risks on the credit risk of corporates over time. By applying this framework with the inputs of the NGFS climate scenarios on 2200 non-financial corporates listed in Hong Kong, it enables us to assess how far climate-related risks may affect the resilience of the corporate sector in Hong Kong over a 30-year time horizon under various NGFS reference scenarios. This forward-looking scenario analysis can further identify which types of sectors and firms may be the most vulnerable to climate-related risks. **This analysis strengthens our systemic risk analysis on climate-related issues and shows our commitment to supporting the NGFS Glasgow Declaration**.[2]

Overall, our analysis suggests that the credit risks arising from climate-related risks should be relatively manageable for most firms in Hong Kong. That said, some firms, especially those from emissions-intensive sectors, could face material transition risks and, therefore, may be subject to a notable rise in credit risks under the disorderly transition scenario. Our findings also show that from a long-term perspective, the impacts of climate transition risks on firms' default risks would be significantly smaller in the "orderly transition" scenario than the "disorderly transition" scenario. In addition, we find that the impact of physical risks under these two transition scenarios would be lower than the "no action" case. On the whole, these results together support the conclusion that there are clear benefits in taking climate actions, and acting early.

[1] The pilot CRST was launched in January 2021 with 27 participating banks. In December 2021, the HKMA published the results of the pilot banking sector climate risk stress, which showed that climate risks could potentially cause significant adverse impacts on the banking sector under extreme climate scenarios although the banking sector would remain resilient given banks' strong capital buffers. For details, see "Pilot Banking Climate Risk Stress Test", HKMA, 30 December 2021.
[2] The HKMA issued a statement in November to support the NGFS Glasgow Declaration. For details, see "Supporting the Central Banks and Supervisors Network for Greening the Financial System Glasgow Declaration", HKMA, 3 November 2021.

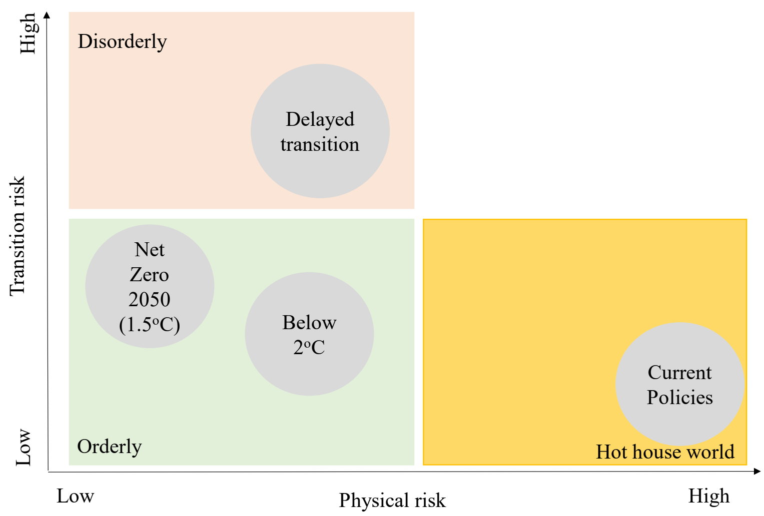
The paper is organised as follows. Section 2 describes the different NGFS scenarios considered in this study, and sets out the associated pathways of the main drivers of transition and physical risks under each of these scenarios. Section 3 provides an overview of the analytical framework and the key transmission channels through which transition and physical risks could affect corporates' financial fundamentals. Section 4 describes the sample of firms considered in this analysis and highlight the stylised features of these firms. Section 5 presents the key results. Section 6 concludes.

2. Overview of the NGFS reference climate scenarios considered

2.1 Descriptions of different NGFS scenarios

This analysis will consider four different NGFS scenarios, which vary in the levels of their transition and physical risks. Specifically, these scenarios can be broadly classified into three main categories, namely (i) orderly transition, (ii) disorderly transition and (iii) hot house world. A graphical illustration of these scenarios, on their level of transition and physical risks, is presented in Chart 1.

Chart 1: Comparison of transition and physical risks under different NGFS scenarios



Source: Modified chart based on NGFS.

Orderly transition

Under the orderly transition category, climate policies (such as a carbon tax) are assumed to be introduced in 2020 and become more stringent over time in an orderly manner. As climate mitigation action is taken early to limit the rise in global temperature, the physical risk is assumed to be relatively mild. Two different scenarios are further considered under the orderly transition case, namely **"Below 2°C"** and **"Net Zero 2050"**. The former entails meeting the Paris Agreement targets of well below 2 °C by the end of the century, while the latter can be viewed as the more ambitious scenario that limits global warming to 1.5 °C and reaching net zero carbon emissions by around 2050 through stringent climate policies and innovations on a global scale. As more stringent climate policies will be implemented in the Net Zero 2050 scenario, the associated transition risk is therefore higher (but with a lower physical risk) than that of the "Below 2 °C" scenario.

Disorderly transition

The disorderly transition scenario assumes that policymakers delay the introduction of climate policies until 2030 (also referred to as the "**Delayed transition"**). Due to a delayed implementation of climate policies, more stringent policies would need to be imposed more rapidly to ensure targets are met by the end of 2050, thus causing an abrupt disruption to the economy. As a result, the transition risk would be higher in the disorderly transition scenario than those in the orderly transition from a longer horizon perspective.

Hot house world

This scenario assumes that countries will preserve their currently implemented climate policies until the end of the time horizon (also referred to as the "**Current Policies**" scenario in the NGFS documentation). This would lead to a limited or no transition risk for many countries, but it would however result in severe physical risks as temperatures are expected to rise well above the Paris Agreement target by the end of 2050.

To assess the extent of the transition risk and physical risks across different scenarios, it is useful to construct a hypothetical scenario without climate risks as a baseline case. In view of the advantage of a limited transition risk sustained in the Current Policies scenario, we therefore construct a hypothetical "business-as-usual" baseline scenario based on the Current Policies scenario, and further exclude the impact of physical risks from the temperature rise. Regarding the projection time horizon, similar to many climate risk assessments undertaken by other central banks, this study will consider the transition pathways up to 2050 (i.e. a 30-year horizon).

2.2 Projections of key climate and macroeconomic variables

Based on the individual NGFS reference scenarios considered above, the transition pathways of key variables (such as carbon prices and the corresponding changes in GHG emissions) are generated based on Integrated Assessment Models[3] (IAMs) that integrally simulate the dynamics within and between energy, land-use, economy and climate systems in a forward-looking fashion.[4] In addition, using some of the IAM outputs (e.g. the resulting temperature rise from each scenario) as input variables, the extent of a physical chronic risk is further simulated based on an additional macro-econometric model (e.g. PIK model). In view of the complex and non-linear dynamics among climate and economic variables, the transition pathways of these variables is expected to exhibit large variations across different scenarios. In this subsection, we will examine the transition pathways of some key variables used in our assessment under different scenarios.[5]

Carbon prices and GHG emission

Charts 2 displays the projected average world carbon price under various scenarios. As policymakers are assumed to introduce climate policies immediately under the Below 2°C scenario, the level of the projected carbon price, which reflects the stringency of climate policy, rises gradually over time from 2020 (i.e. the orange line). For the more ambitious Net Zero 2050 scenario, the projected rise in carbon price is much more significant (i.e. the blue line), as policymakers strive to achieve the net zero emissions target on a global basis by the end of 2050. In particular, the carbon price is projected to rise above HK$7,000 per tonnes of CO_2 (at the 2020 price level) by 2050 under the Net Zero 2050 scenario. By contrast, the carbon price under the delayed transition scenario (i.e. the yellow line) follows the same pathway of that under the Current Policies scenario (i.e. the grey line), which remains largely unchanged between 2020 and 2030. From then onwards, there will be an abrupt rise in the carbon price under the delayed transition scenario as policymakers need to impose

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[3] NGFS scenarios have been generated with three well-established IAMs, namely GCAM, MESSAGEix-GLOBIOM and REMIND-MAgPIE. For the technical details on each of the IAMs, see the NGFS technical documents (https://www.ngfs.net/sites/default/files/ngfs_climate_scenarios_technical_documentation__phase2_june2021.pdf) In this study, we focus on the transition pathways generated by the REMIND-MAgPIE IAM framework.

[4] It is worth noting that the latest NGFS phase II scenario data have already been adjusted for the COVID-19 pandemic and its impact on economic system and growth and final energy demand based on projections from the IMF.

[5] It should be noted that there is a number of alternative projections by other institutions. Due to different projection methodologies, their estimates may differ from those under the NGFS reference scenarios.

a more stringent climate policy to ensure the Paris Agreement targets are met by the end of 2050.

Chart 2: Projected average world carbon price

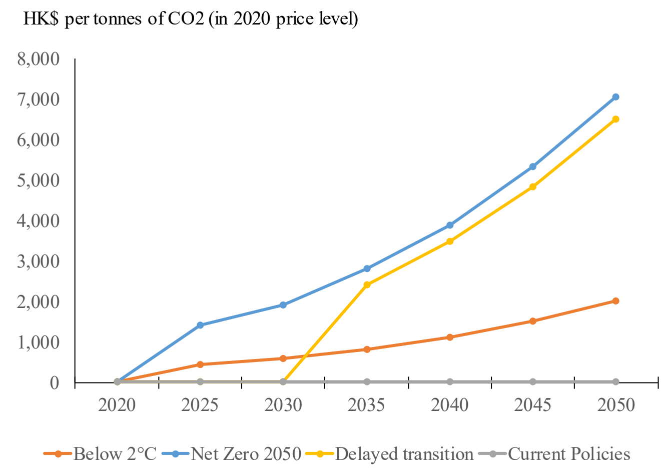
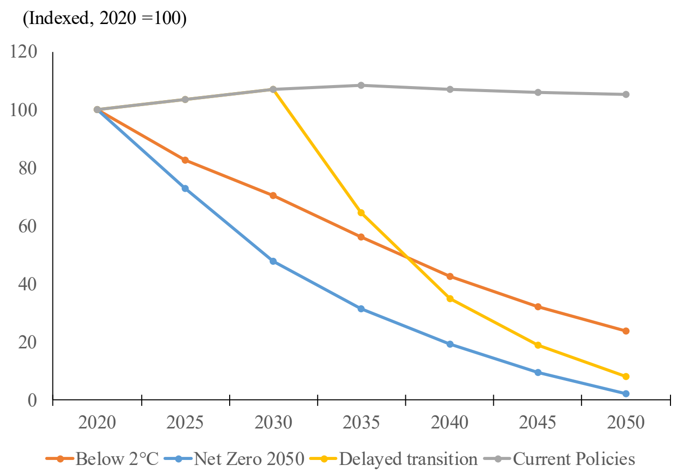


Chart 3: Projected world GHG emissions levels



Source: HKMA staff calculation based on NGFS climate scenarios.

Chart 3 presents the corresponding projection of world GHG emissions (indexed to 100 in year 2020). In response to the introduction of a carbon price, the level of annual GHG emissions is projected to decline in an orderly manner over time under the two orderly transition scenarios (i.e. blue and orange lines). In particular, the fall in annual GHG emissions is much more significant under the Net Zero 2050 scenario, due to the more stringent carbon price imposed, and that the net zero emissions target is largely to be achieved by the end of 2050 (i.e. blue line). In stark contrast, the absence of a carbon price under the Current Policies scenario, means there will not be a sufficient economic force to drive down the level of annual GHG emissions. Instead, there will be a slight rise in the global emissions. Lastly, in the delayed transition scenario, while the level of GHG emissions will only start declining from 2030, it will drop rapidly in response to the abrupt rise in the carbon price. In particular, due to the more significant carbon price rise under the delayed transition, the associated projected level of GHG emissions will thus drop lower than that in the Below 2°C scenario at the end of the projected horizon (i.e. yellow line).

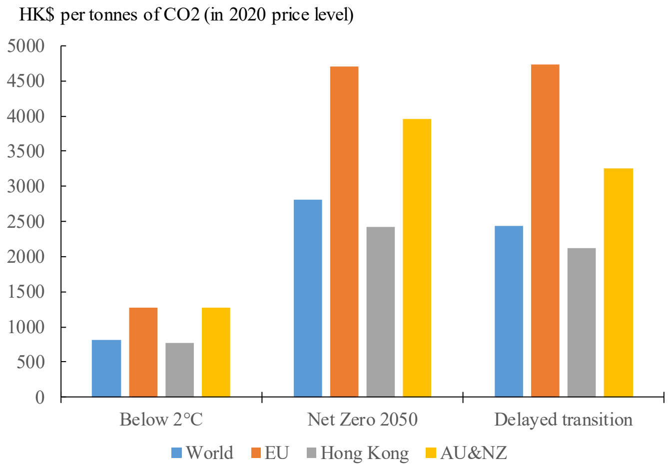
It is noteworthy that the transition pathways of carbon prices not only exhibit large variations across scenarios, but also differ across regions and countries under the same scenario. This can be seen in Chart 4 which compares the projected carbon prices for Hong Kong[6], Europe and Australia & New Zealand under various scenarios by the end of 2035 (panel A) and the end of 2050 (panel B),

[6] The carbon price for Hong Kong is generated through the down-scaling methodology by the outputs derived from the China regional IAM model. Therefore, the projected carbon price for Hong Kong is the same as that for China.

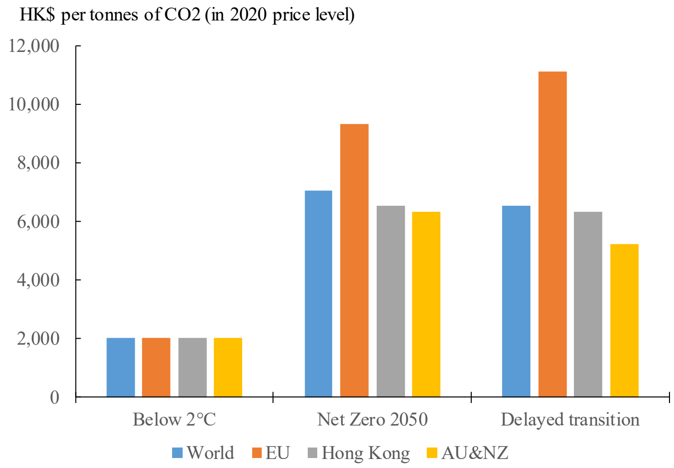
respectively. Likely reflecting differences in economic structure and institutional factors, the projected levels of carbon prices are generally different across regions.

Chart 4: Projected carbon prices across selected regions

Panel A: End-2035



Panel B: End-2050



Source: HKMA staff calculation based on NGFS climate scenarios.

In view of the cross-country differences in the projected carbon prices, we adopt the following procedure to estimate firms' operating expenses stemming from carbon emissions for those with multiple business locations. We first identify the operating locations of each firm based on its revenue share by geographical breakdown. We then compute the expense of a firm's carbon emissions in each business location by multiplying the carbon price and its carbon emissions in that business location. The firm's aggregate operating expenses for carbon emissions are then derived by summing up such expenses across all business locations.

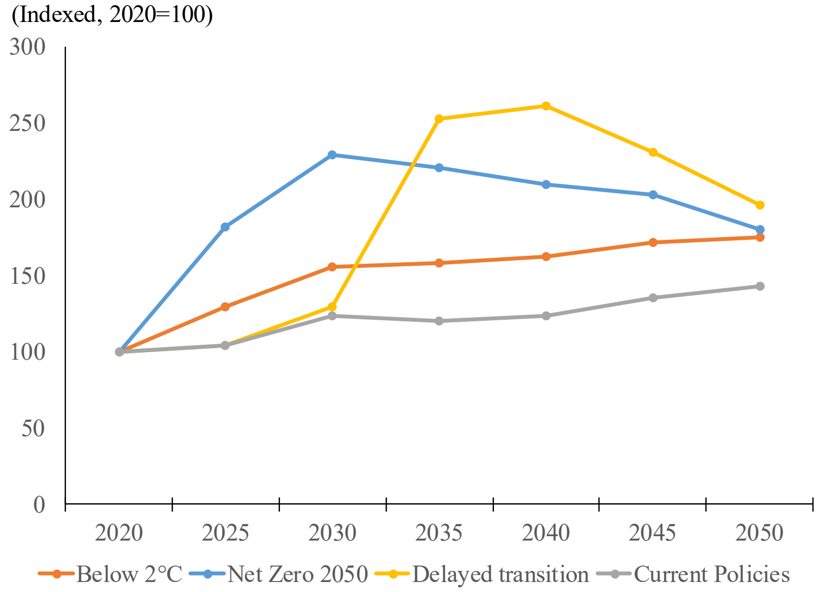
Energy prices

The transitioning away from fossil fuel energy towards more renewable energy sources will alter the pattern of energy supply and demand, thereby affecting future energy prices. Chart 5 presents the projection of the average world secondary energy price[7] across the four scenarios. Under the orderly transition scenarios (i.e. Below 2 and Net Zero 2050), there will be a notable jump in average energy prices during the first 10 years, largely reflecting higher energy production costs during the early stages of transition. As green energy will be used more broadly in the economy and also produced relatively more efficiently over time, the rise in energy prices will eventually peak and then gradually trend downwards under the Net

[7] Secondary energy refers to the energy sources transformed from primary energy (i.e. fossil fuel, solar, oil, natural gas and nuclear fuels). Secondary energy sources include electricity and heat, petroleum products, manufactured solid fuels and gas, and bio fuels etc.

Zero 2050 scenario. By contrast, given a delayed and abrupt adoption in green energy production technologies under the delayed transition scenario, there will be a sharp rise in the projected energy prices from 2030. Although the average energy price will eventually be lower over time, it will remain highest among other scenarios by the end of 2050. Lastly, for the Current Policies scenario, as there will be no significant change in the pattern of energy mix, the average energy price is projected to rise relatively mildly across the whole projection period.

Chart 5: Projected average world secondary energy price



Source: HKMA staff calculation based on NGFS climate scenarios

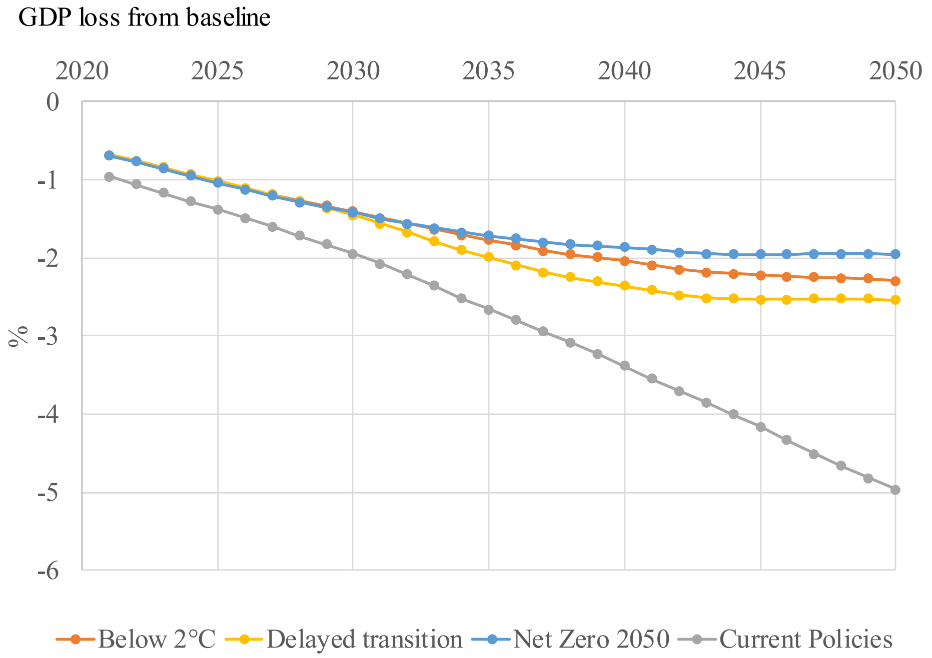
GDP loss incurred from physical chronic risk

Despite the implementation of climate policies to combat climate change, the global mean temperature is still assumed to rise in all NGFS scenarios. The temperature rise will lead to chronic changes in living conditions, thereby affecting the labour productivity and result in GDP loss. According to the NGFS, the associated GDP losses from the temperature rise are calculated based on the methodology set out in Kalkuhl and Wenz (2020) at the country level.[8] In this study, we consider the negative impact of the temperature rise in China as the main physical risk driver on firms' credit risk in view of the significant Chinese exposure in our sample of firms listed in Hong Kong. Chart 6 displays the projected annual GDP loss in China resulting from the temperature rise. As the rise in the global mean temperature is projected to be limited to below 1.5°C to 2°C under both orderly and disorderly transition scenarios, the associated annual GDP losses relative to the

[8] The methodology does not include impacts related to extreme weather, sea-level rises or wider societal impacts from migration or conflicts.

baseline are estimated to be relatively mild, at around 2% at the end of 2050. However, the negative impact in the Current Policies scenario is much more significant, with the annual GDP being 5% lower relative to the baseline at the end of 2050, as the temperature rise is projected to exceed 3°C under such scenario.

Chart 6: Projected annual GDP loss in China from physical chronic risk

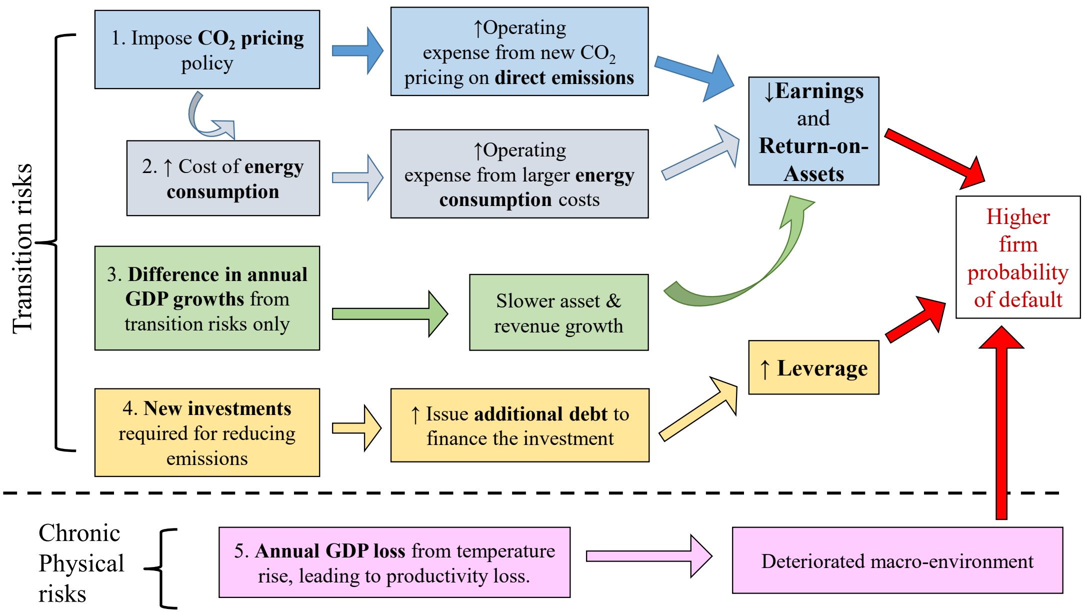


Note: Following the NGFS's practice, the 95th percentile of the projected GDP loss stemming from the temperatures rise is used for the "Current Policies" scenario, while the expected values are used for the other three transition scenarios.
Source: HKMA staff calculation based on NGFS climate scenarios

3. OVERVIEW OF THE ANALYTICAL FRAMEWORK

In this section, we provide an overview of the analytical framework and the key transmission channels through which climate-related risks could influence firms' financial fundamentals and hence their default risk. The technical details of the relevant models and projection procedures are presented in the Annex. The schematic overview of the framework is illustrated in Chart 7.

Chart 7: Schematic overview of the analytical framework



The climate transition risks could affect firms' profitability and leverage as follows. First, as carbon prices are assumed to be imposed on firms' direct GHG emissions (i.e. carbon tax) under the NGFS scenarios (i.e. blue parts in the chart), firms will not only face higher operating expenses directly from the carbon tax on their emissions, but also indirectly from higher energy consumption costs (i.e. grey parts).[9] Both could put downward pressure on firms' profitability. In response, firms are assumed to lower their emissions and shift towards using more green energy in their production to mitigate the impacts on their profitability as mentioned earlier. In essence, the net impact on firms' profitability is determined jointly by the paths of carbon and energy prices and the associated change in firms' emissions over time.

Second, the adjustment in production by firms in response to the introduction of a carbon tax and the associated effects on energy prices will result in slower

[9] Higher carbon taxes will increase prices of energy generated from fossil fuel combustions. If consumers cannot substitute by switching easily to cheaper and greener renewable energy sources, they will then face higher indirect energy consumption costs. While there is smaller consensus on whether such an outcome will ultimately occur, policymakers are starting to focus on the financial stability implications of a possible case of a persistently higher energy price environment as driven by green transitions (for example, Schnabel 2022).

economic growth, which in turn will negatively affect firms' revenue and asset growth (i.e. green parts in the chart). [10]

Third, firms are assumed to invest in more sustainable production technologies to achieve a target of GHG emissions reduction. Such investment is assumed to be financed by new debts, leading to higher leverage (i.e. the yellow parts of the chart).

On physical risks, our analysis captures the macro impact of global temperature rises, which leads to lower productivity and output loss, thereby affecting firms' financial fundamentals (i.e. pink parts of the chart). While firm's specific exposure to physical risks are important, the impact cannot be assessed in the current analysis due to data limitations.[11] Further refinements in the future are possible after addressing the data gaps.

With the transmission channels discussed, we can assess how different NGFS scenarios will affect firms' profitability, leverage and macro environments over a 30-year horizon. Using these estimates, we can further assess the impact on a firm's 1-year default probability (PD)[12] based on a satellite model that empirically explains the PD of a firm by its return on assets, debt-to-assets, size and the macro environments measured by the output gap. Details of the projection of firms' future environment costs and the specification of the satellite model are presented in Annexes A and B, respectively.

4. DATA

Our samples include all non-financial firms listed in Hong Kong. The sample contains around 2200 firms in total[13]. Firm-level financial information is obtained from S&P Capital IQ and Bloomberg. Firm's industry classification, organisational structure, state ownership share, and geographical breakdown of revenue share are also sourced from S&P Capital IQ.

We gauge the exposure of firms to the transition risk by their GHG emissions through data obtained from *S&P Trucost.* Consistent with the standards set out by the

[10] Here, the slower GDP growth is only attributable to transition risks which do not include the impact of physical risk.

[11] Apart from chronic risk, physical risks can also arise from extreme weather events (e.g. storm, drought-risks) which would pose direct financial losses on firms' assets that are exposed to these extreme events. However, quantifying such financial impact requires detailed locations data of firms' assets and activities, which are not readily available.

[12] 1-year ahead probability of default by Bloomberg is chosen to proxy for the default risk.

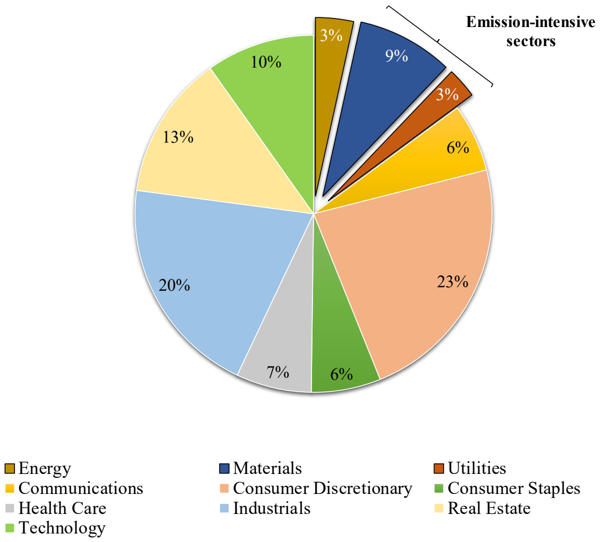
[13] Among them, around 790 of listed firms are domiciled in Hong Kong, while the rest are domiciled outside Hong Kong.

GHG Protocol[14], three types of GHG emissions data of a corporate are available from *S&P Trucost* - namely scope 1, 2 and 3 emissions. In general, scope 1 emissions cover all emissions generated during fuel combustion activities from a firm (or its controlled affiliates) while scope 2 emissions cover indirect generation relating to the purchase of energy. Scope 3 emissions include all other indirect emissions that occur in a company's value chain. As scope 3 emissions are usually not available for most of our sampled firms, this type of emission is disregarded in our analysis. More specifically, we obtain the latest available emissions data for each Hong Kong-listed firm between fiscal year 2018 and 2020 for the analysis. For those Hong Kong-listed firms whose emissions information is not available in Trucost, the corresponding industry average values of scopes 1 and 2 emission intensities for all globally listed corporates are used to estimate their emissions levels.

4.1 Firm distribution

Chart 8 presents the share of firms by sector. Firms from emission-intensive sectors, namely energy, materials and utilities sectors, account for 15% of the sampled firms. Consumer discretionary represents the largest share (23%) of the sample, while the energy and utilities sectors accounted for the smallest share (at around 3% each).

Chart 8: Distribution of sampled firms by sector



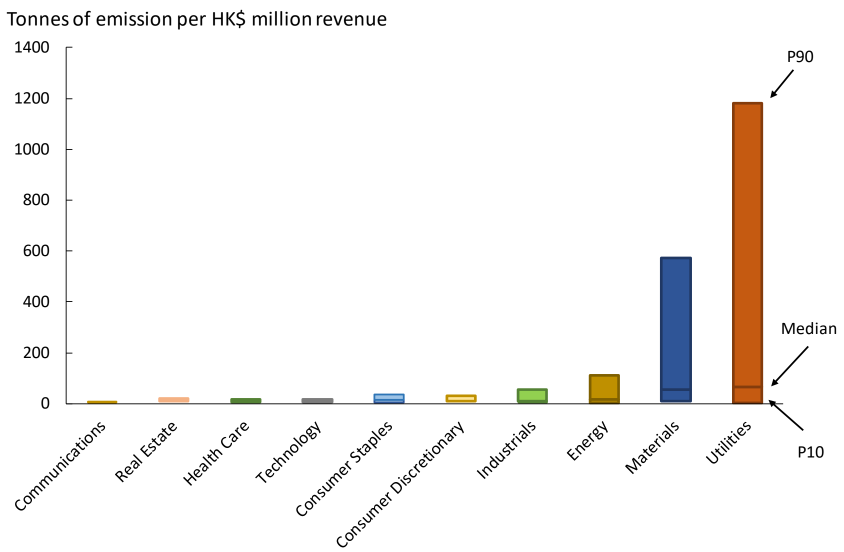
Source: HKMA staff calculation based on S&P *Trucost* data.

4.2 Emissions intensity

[14] The GHG Protocol is considered to be the most widely recognised international accounting tool for the measurement of GHG emissions.

Chart 9 depicts the distribution of firms' emissions intensity (calculated based on their scope 1 and scope 2 emissions relative to revenue)[15] across different sectors. Each bar presents the 10th percentile, median and 90th percentile of the sampled firms' emission intensities. There are two key observations. First, there are large differences in emission intensities (i.e. relative to revenues) across firms from emission-intensive sectors. Second, in many sectors, the 90th percentile stays far above the median, suggesting that the transition risks facing a "brown" firm could be much higher than its peers within the same sector.

Chart 9: Emissions by sector

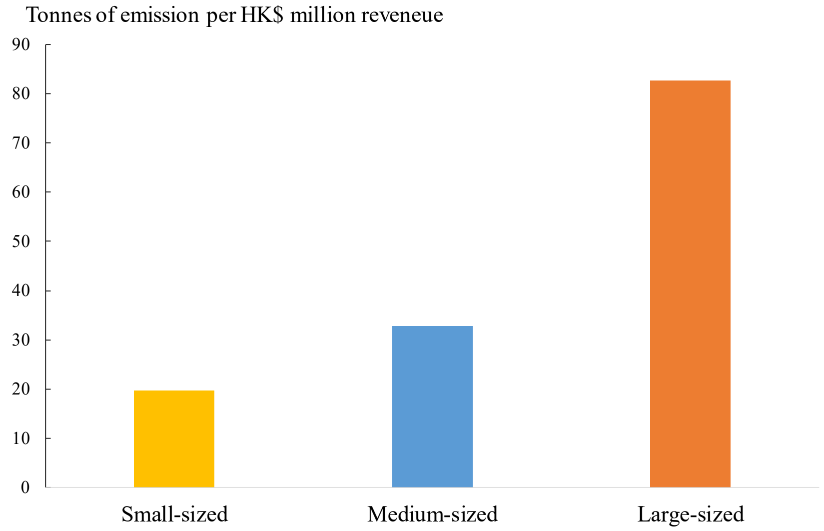


Source: HKMA staff calculation based on S&P *Trucost* data.

Chart 10, which displays the simple average of emission intensities by firm size, finds a positive correlation between firm size and the emission intensity. Large-sized firms, on average, have much higher emission intensity than small-sized firms (i.e. 85 versus 20 tonnes of CO_2e for each Hong Kong dollar of revenue).

Chart 10: Emissions by firm size

[15] When evaluating a firm's exposure to transition risks, its emission intensity is more meaningful than its emission levels, as the former takes into account the firm's scale of economic activities.



Source: HKMA staff calculation based on Bloomberg and S&P *Trucost* data.
Notes: Firms are categorised as small, medium and large based on the size of their total assets. Firms below the lower quantile are labelled as small, those above the upper quantile are labelled as large and the rest are medium.

5. RESULTS

In this section, we will first discuss the estimated impact of transition risk on firms' default risk under various scenarios, followed by discussions on the estimated impact of physical risks. As mentioned earlier, the estimated impacts under each scenario will be assessed against the hypothetical baseline scenario.

5.1 Impact of transition risks

5.1.1 Impact of transition risks on a typical firm in Hong Kong

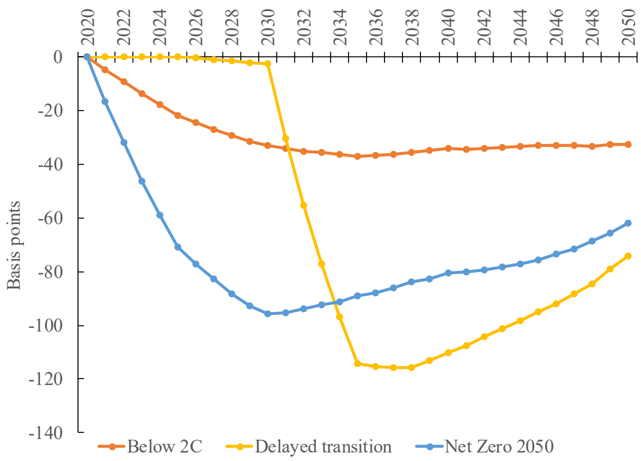
Overall, the transition towards a low carbon economy is found to lead to lower profitability and a higher leverage of firms relative to the baseline case. However, the size of the impact is crucially dependent on the path of transition (i.e. orderly or not) and the GHG emissions profiles of individual firms.

We first assess how the financial performance, and hence default risk of a "typical" firm, will be affected under various transition scenarios by focusing on the median impact for all sampled firms over time. Chart 11 depicts the median impact on firms' profitability (as measured by ROA) and leverage (as measured by debt-to-asset ratio). As climate policies are taken early in the orderly transition scenarios (i.e. Below 2°C and Net Zero 2050), firms will typically register a lower ROA and higher leverage in the first 10 years of the projection horizon, compared with that under the delayed transition scenario. However, with firms shifting towards greener production and reducing their GHG emissions accordingly, these negative impacts will gradually recede over time.

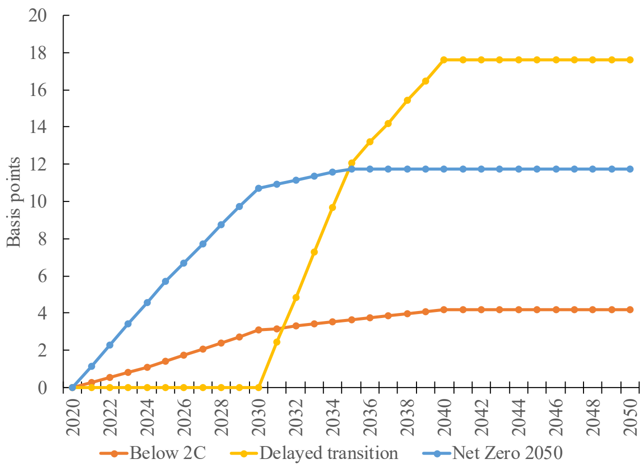
By contrast, under the delayed transition scenario where firms' profitability and leverage would not be affected in the first 10 years, these short-term benefits would come at the expense of a larger decrease in ROA and a sharper rise in leverage after 2030, due to an abrupt transition.

Chart 11: Projected effect of transition risks on profitability and leverage for the median firm relative to the baseline

a) <u>Median impact on profitability (ROA)</u>



b) <u>Median impact on leverage (Debt-to-Asset)</u>



Source: HKMA staff calculation

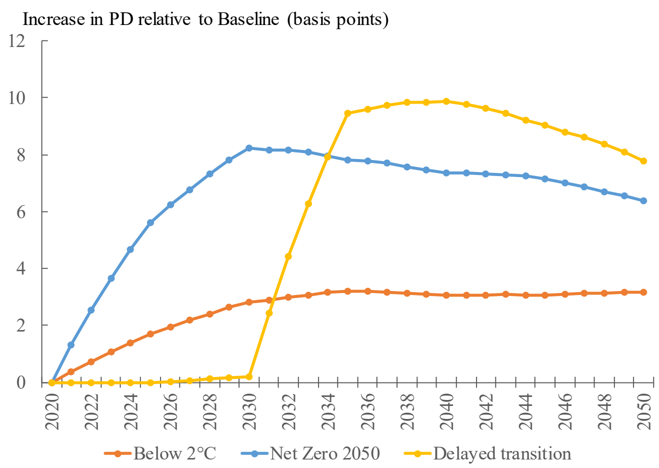
A lower profitability and higher leverage will together translate into a higher probability of default (PD) for firms. Panel A of Chart 12 displays the estimated median change in PD relative to the baseline. The median change in PD is projected to rise above the baseline case in the range of +3bps to +8bps in the first 10 years before trending down gradually under the two orderly transition scenarios (i.e. blue and orange lines). For the delayed transition, the median change in PD is projected to rise from 2030 onwards, which could increase by as high as 10 bps above the baseline case in 2035. Despite the slight decline after 2035, it would remain higher than that of the orderly scenarios by 2050. Although the impact on default risk is found to be mild under the three scenarios, the results show the long-term benefit of an orderly transition.

To further account for the effect of firm size, panel B of Chart 12 presents the average change in PD (weighted by firms' assets). While the overall trend for the weighted impact remains similar to that for the median impact, the size of the weighted average rise in PD is notably larger than the median impact across all scenarios. For instance, the weighted average change in PD could rise as high as 45 bps relative to the baseline case in 2035, compared with the median rise of 10 bps in the same period, under the delayed transition scenario. **This finding suggests that the default risk of larger firms would tend to be more adversely affected by the transition risks, in part, reflecting the higher average emissions intensity for larger firms (see Chart 10).**

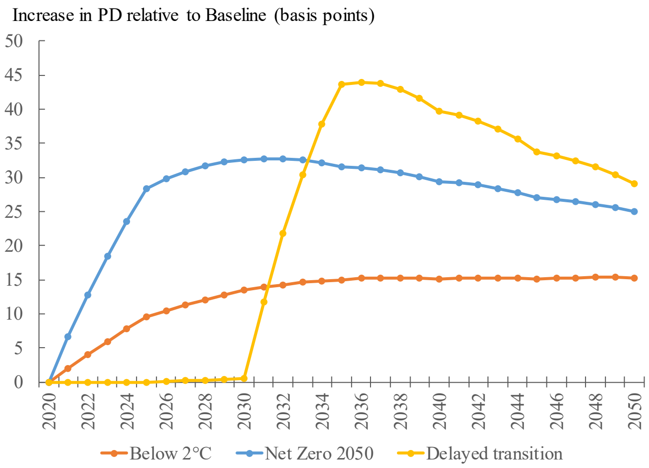
However, it is important to note that the projected impact on ROA, leverage and PD for a typical firm appear to be relatively mild given that the historical sampled mean of these variables is 4%, 21% and 2% respectively. This is primarily driven by the fact that a vast majority of firms listed in Hong Kong are not from emissions-intensive sectors (see section 4), and thus may be less subject to high transition risks.

Chart 12: Projected change in firms' PD relative to the baseline case

Panel A: Median impact



Panel B: Average impact (weighted by assets)



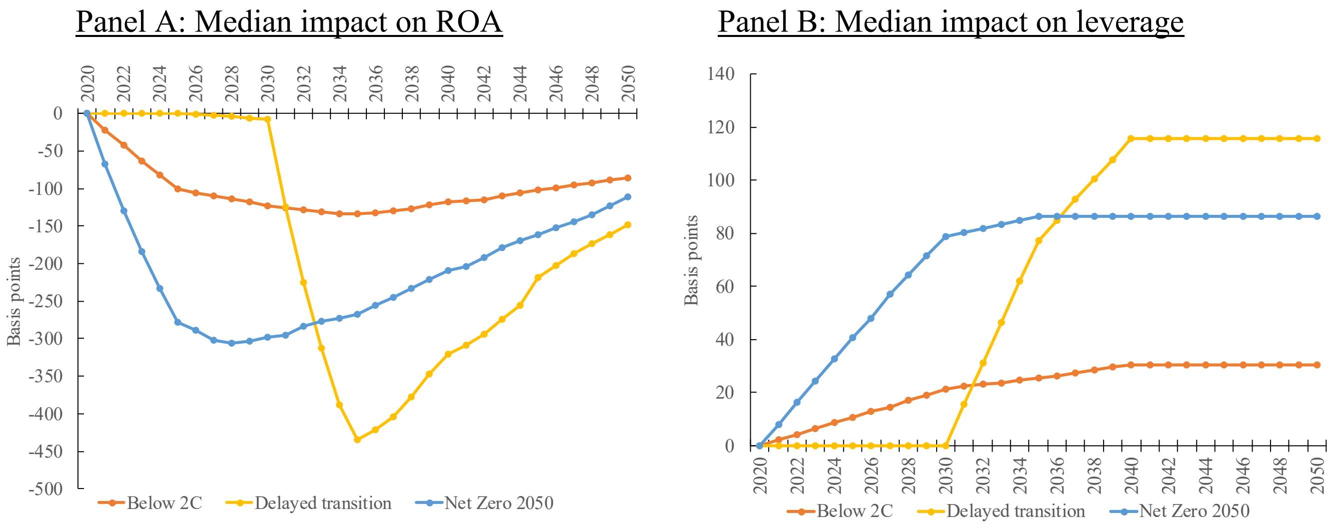
Source: HKMA staff calculation

5.1.2 Impact of transition risks on firms from emissions-intensive sectors

Given the above median analysis on all sampled firms may mask the impact on firms that are more exposed to transition risks (especially those highly emitting firms), this subsection will thus focus on the results for firms from the three emissions-intensive sectors.

Chart 13 presents the median impact of transition risks on the profitability and leverage of firms from emissions-intensive sectors under different scenarios. **As firms from emissions-intensive sectors will be more likely subject to the effect of carbon prices, and also requiring more investments on green technology to achieve the necessary transition, they tend to experience a more significant drop in ROA and a larger increase in leverage than a typical firm.** Taking the delayed transition scenario as an illustration, the median change in ROA for highly-emitting firms is projected to drop by close to 450 bps relative to the baseline in 2035, which is equivalent to almost four times the impact for the typical firm under the same scenario. Although the profitability will gradually improve over time under the three scenarios at the end of 2050, the fall in ROA remains large, ranging between -85 bps and -150 bps relative to the baseline. Given the historical sampled mean of ROA for highly emitting firms is 3.5%, this suggests that highly-emitting firms will likely face significant downward pressure on their profitability under both the orderly and disorderly transition.

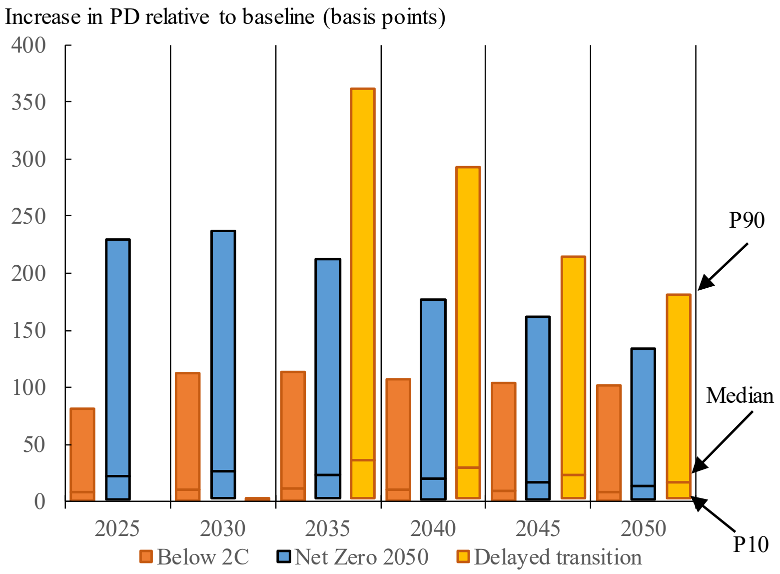
Chart 13: Projected changes in profitability and leverage relative to the baseline for firms from emissions-intensive sectors



Source: HKMA staff calculation

Chart 14 displays the distribution of the resulting change in PD for highly-emitting firms relative to the baseline under the three scenarios. Each bar presents the 10th percentile and 90th percentile and the median change in the firm's PD. The orange and blue bars represent the impacts under the orderly transition (i.e. Below 2°C and Net Zero 2050, respectively), while the yellow bars are those under the delayed transition scenario.

Chart 14: Projected change in the PD relative to the baseline for firms from emissions-intensive sectors



Source: HKMA staff calculation

Three key findings are worth highlighting. **First, the impact of transition risks on the default risk of firms is generally more significant for those from emissions-intensive sectors, as compared with that of the typical firm.** As firms from emissions-intensive sectors will see a more tangible decline in ROA and a higher leverage than a typical firm, the median rise in PD relative to the baseline is, therefore, much more pronounced across all three scenarios. In particular, the median change in PD for firms from the emissions-intensive sector could rise as high as 25 bps and 37 bps relative to the baseline in 2035 under the Net Zero 2050 and delayed transition scenarios respectively. This is significant given that the change in the median level of PD for all listed firms in Hong Kong during 2019-2020 was around 37 bps.

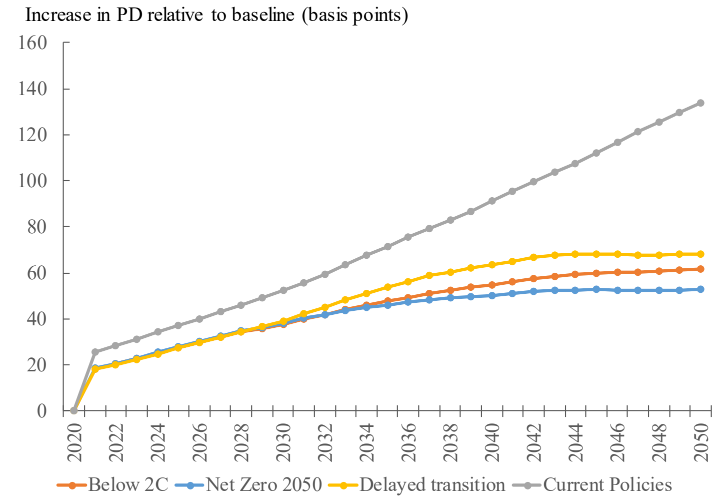
Second, a large cross-sectional variation exists in the extent of the rise in PD among firms from emissions-intensive sectors, suggesting that sector-level estimates may not be reliable in gauging the impact of transition risks for individual firms. Taking the delayed transition in 2035 as an example, while the median change in PD is found to be around 37bps, the change in PD could range widely from a low level of 4 bps at the 10^{th} percentile to around 360 bps at the 90^{th} percentile. One key implication is that it is crucial to take into account firm specific information, such as its climate risk disclosures and business nature, in order to have an accurate assessment of climate-related risks on firms.

Third, the longer term impact of transition risk on firms' default risk is also found to be substantially smaller in the orderly transition scenarios than in the delayed transition scenario for firms from emissions-intensive sectors. In particular, for highly-emitting firms (i.e. at the 90^{th} percentile), their PDs could rise by around 180 bps relative to the baseline by the end of 2050 under the delayed transition scenario, while the corresponding estimates under the Below 2^{o}C and Net Zero 2050 scenarios are around 100 bps and 135 bps respectively.

5.2 Impact of physical risks

The impact of chronic physical risks through the GDP loss arising from the temperature rise (i.e. the macro channel) is assessed in this section. This macro channel captures the impact of a rise in global temperature on GDP loss due to lower labour productivity. The impact of the GDP loss will then be translated into firms' PD. Due to data limitations, however, the impact of physical risks on firm-specific exposures cannot be captured in this analysis.

Chart 15: Projected effect of physical chronic risk on firms' PD



Source: HKMA staff calculation

Our assessment shows that the impact of physical risk under the three transition scenarios would be much lower than that of the Current Policies scenario (i.e. the Hot House World) (Chart 15). In particular, the temperature rise is assumed to exceed 3°C under the Current Policies scenario which triggers a significant GDP loss. The high physical risk could lead to a significant rise in firms' median PD by around 130 bps in 2050. By contrast, under both orderly and disorderly scenarios where climate policy actions will help keep the rise in global temperature to well below 2°C by 2050, the corresponding rises in firms' median PD is found to be lower than that under the Current Policies scenario by around 65 to 80 bps, pointing to a long-term benefit of adapting a green transition as opposed to the "no action" case.[16]

It is important to point out that the above estimates on the default risk of firms may be prone to underestimation, as many other types of physical risks (such as direct financial losses from extreme weather events) have not yet been captured in the current analysis. Therefore, the total impact of physical risks on firms' default risk could be much higher than the current estimates, particularly for those firms whose assets are more exposed to extreme climate events (e.g. firms with plants located near the sea coast). Therefore, the above estimates should be interpreted cautiously.

6. Conclusion

This study presents a top-down framework for assessing the impact of climate-related risks on firms' credit risks using the NGFS reference scenarios. Overall, our

[16] Compared with Below 2°C scenario, the impact of physical risk on firms' PD is found to be smallest under the Net Zero 2050 scenario, as the global mean temperature rise is assumed to be limited to below 1.5°C given the implementation of more stringent climate policies.

analysis suggests that the credit risks arising from climate-related risks should be relatively manageable for most of the firms in Hong Kong due to the fact that most listed firms are not from emissions-intensive sectors. However, some firms from emission-intensive sectors, could be subject to a notable rise in credit risks under the disorderly transition scenario. Regarding the implications for the Hong Kong banking sector, while the transition risks may become a source of credit risks of banks' loan portfolios, the impact could be different across banks depending on the sectoral composition of their loan portfolios. Nonetheless, the Hong Kong banking sector as a whole is not heavily exposed to emission-intensive sectors. Importantly, underpinned by the strong capital position, the Hong Kong banking sector should remain resilient to the climate transition risks.

Another important finding is that from a long-term perspective, the impact of climate transition risks on firms' default risks would be significantly smaller in the "orderly transition" scenario than the "disorderly transition" scenario. In addition, we also find that the impact of physical risks under these two transition scenarios would be lower than the "no action" case. Together, these results demonstrate there are clear net benefits in taking climate actions, and acting early.

However, cautions should be exercised when interpreting the results as there are several limitations in the current analytical framework. First, data gap issues prelude us from fully assessing the climate-related risks, for example, physical risks of firm specific exposure.[17] Second, the estimates for a long time horizon (up to 2050) could be subject to large uncertainties. Lastly, due to the lack of reliable environmental data for non-listed firms, the current analysis cannot assess the impact of climate risk on small-and-medium enterprises.

[17] Apart from data gap related to physical risk, other key data gaps may include the opportunities in transition, such as higher demand driven by consumer green preferences, improved energy efficiency and operational flexibility. These factors could potentially result in improvement in firms' profitability.

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Annex A: Details on constructing emissions level, carbon prices, and investment costs for emissions reductions and the cost of indirect energy consumption

This annex describes details of how the various future costs faced by firms are projected. It covers firms' future emissions level, future carbon prices, cost of investments for emissions reduction, and the cost of indirect energy consumption. The information is based on their existing financial and environmental information together with the NGFS climate scenario data.

1. Emission level

Transitioning away from fossil fuels and carbon-intensive production requires a substantial shift towards carbon-neutral alternatives in all sectors. Nevertheless, the extent to which carbon-intensive productions can lower emissions will hinge on the future availability of alternative green technologies. In view of this, the second iteration of the NGFS scenarios (NGFS 2021) is enriched with additional granular data regarding the future emissions of carbon-intensive production. As the extent of emission reduction varies significantly across these carbon-intensive productions, the emission paths of firms are, therefore, calibrated with reference to their business nature and their mapped sectors. More specifically, the future emissions of firms are calibrated based on the sectoral mapping as shown in Table A1, using the emission level path from the "World" region. For firms in other sectors that are not shown in the table, as their main emission sources are typically from the consumption of electricity, their future emissions path is thus calibrated to follow the revenue-weighted country-level emission reductions.

Table A1: Mapping of firms in emission intensive sectors to carbon-intensive production in NGFS IAM models

GICS sector	GICS Industry Group/ Primary industry	Carbon-intensive productions in NGFS IAM models
Utilities	Electricity Suppliers	Electricity supplier
Utilities	Other non-electricity firms	Energy Supply
Energy	Energy Equipment and Services / Oil, Gas and Consumable Fuels	Energy Supply
Industrials	Transportation	Transportation

Materials	Construction materials	Industrial Processes (Cements)
Materials	Chemicals, Metals and Mining, others	Industry (Chemicals, Steel, etc)

Note: This proposed mapping is a highly simplified version of the reality, with consideration for preserving modelling simplicity for a sizable number of firms. As firms (particularly larger firms) may be involved in multiple business segments, it is suggested that during the assessment process a more comprehensive review on firms' business nature should be taken to better gauge the climate-related risks they face.

2. Carbon prices

Each firm faces different carbon prices according to the firm's own revenue share by geographical breakdown. S&P Capital IQ provides countries geographic breakdown of revenue for Hong Kong-listed firms. Matching this information with the definition from NGFS Technical Documentation V2.2[18] , we calculated the share of revenues generated in each model region.

$$Revenue\ share\ from\ Region\ A = \frac{\sum Revenues_{countries\ within\ region\ A}}{Total\ Revenues}$$

Multiplying the firm specific revenue share with the carbon prices from each region, we obtained the weighted carbon price faced by the firm.

$$Weighted\ carbon\ price = \sum (Rev\ share\ from\ Region\ i * carbon\ price\ from\ Region\ i)$$

Lastly, we computed the carbon cost faced by the firm by multiplying the weighted carbon price with the firm's revenues.

3. Cost of investment for emission reductions

The NGFS scenarios portal has provided annual investment amounts needed for meeting emission reduction targets under respective climate scenarios with reference to McCollum et al. (2018). In order to deviate from the current reliance on fossil fuel

[18] Table A1.3 Regional definition of the REMIND-MAgPIE model is used to map countries' ISO codes into model regions.

combustion under the three transition scenarios, a larger investment amount is required to finance the wider availability of alternative and greener energy sources. Based on the information, and also the respective paths of emission reduction amounts for the entire world across future horizons, we can proxy an average unit investment cost for each ton of emissions reduction under each scenario.

In our current setting, it is assumed that there is no additional investment needed for firms to finance green transitioning under the "Current policies" scenarios. To calculate the additional cost of investment needed for each of the transition scenarios, the following three steps are taken. First, as the investment amount under the Current Policies scenario is smaller than in other scenarios, the additional investment amount needed under a particular scenario is calculated by taking the difference between the amount of investment under that scenario, and the one under the Current policies scenario. Second, we calculate the associated additional reduction in emissions arising from the increased investment relative to the Current Policies scenario. Lastly, the additional unit cost of investment (i.e. the unit replacement cost in equation (15)) is then calculated as the additional amount of investment divided by the associated additional reduction in emissions under each of the three transition scenarios.

In addition, the unit cost of investment is calculated for every 5-year period over the future horizons, in line with the time frequency of the NGFS data.

4. Cost of indirect energy consumption

While many firms have also disclosed their indirect energy consumption level alongside their emission levels in the annual report, such data is not readily available in S&P *Trucost* and some other data providers. We adopted the following approach to derive the change in the cost of indirect energy consumption for each individual firm. We proxy a firm's indirect energy consumption using their scope 2 emissions and information from IEA (2019).[19]

Next, a firm's future energy consumption path is assumed to follow the dynamics of the secondary energy level path under the "World" region for each scenario. Indeed, the implementation of the carbon pricing policy will lead to a more efficient use of energy for all users, so indirect energy consumption levels are

[19] More specifically, we apply this formula to derive the amount, where CO_2 emission per unit of Kwh for the World is from IEA (2019).

$$Indirect\ energy\ consumption\ (GJ) = \left(\frac{Firm's\ total\ Scope\ 2\ emission(tonnes)}{CO_2\ emission\ per\ unit\ of\ Kwh\ for\ the\ World}\right) * (Kwh\ to\ GJ\ factor)$$

expected to be lower in all three transition scenarios than in the “Current policies” scenario.

For the energy unit price, we drive the weighted average unit prices of secondary energy in future horizons by using information about the “shares of types for generating secondary energy” and “unit prices of types for generating secondary energy”. As shown in Chart 5, the unit energy prices paid under the three transition scenarios are found to be higher than that of the “Current Policies” scenario.[20]

Finally, the total cost of indirect consumption for each firm is the product of the energy consumption level and unit energy prices in every future year. As firms have already included the current cost of energy consumption in their current operating expenses, we add the change in cost relative to year 2020 to arrive at a firm’s total cost of indirect energy consumption for each future year.

[20] Reflecting the transmission of higher carbon prices to secondary prices under the three transition scenarios, consumers will ditch energy provided from fossil fuel type and switch towards energy provided from electricity and other greener sources (but in different degrees with respect to the stringency of carbon pricing policy), which costs less than that of fossil types after including the effect of carbon pricing in the respective transition scenarios. However, comparing the unit energy price across scenarios also revealed that the entailed supply expansion to meet the higher demand for greener sources would also lead to higher equilibrium energy prices in transition scenarios, relative to the “Current policies” scenario.

Annex B: Analytical framework

This section describes the analytical framework in more detail. In sum, the analytical framework consists of two main building blocks, namely the estimation block and the projection block. As shown in the main text, the climate-related risks can potentially affect firms' profitability, leverage, and hence the default risk. A set of panel regression models are employed in the estimation block to capture the historical relationships between firms' assets, revenue, operating expenses and GDP growth. Subsequently, these estimates will be used in the projection block to project the impact of climate-related risks on firms' financial fundamentals for future years based on the NGFS reference scenarios. In what follows, we will first display the key sets of panel regressions used in the estimation block and then describe the key steps taken in the projection block.

Estimation block

In the following equations, the subscript or superscript i denotes the firm, t denotes the time (year) and s denotes the scenario. Scenario does not come into play during the estimation stage and only affects the results for the projection stage.

- Profitability

$$Profitability_s^{i,t} = \frac{Earnings_s^{i,t}}{Total\ assets_s^{i,t}} \quad (1)$$

Profitability is defined as earnings over total assets.

- Earnings

$$Earnings_s^{i,t} = Revenues_s^{i,t} - OpEx_s^{i,t} \quad (2)$$

Earnings are defined as operating earnings: revenues minus operating expenses.

- Revenues growth rate

$$\%\Delta Revenues_s^{i,t} = \beta_0 + \beta_1 \%\Delta TA_s^{i,t} + \beta_2 \%\Delta GDP_s^t + \beta_3 t + \varepsilon_s^{i,t} \quad (3)$$

Revenues capture how differences in total assets growth rate from climate policies may impact firms. In this setup, climate policies have two channels on revenues growth rate. Firstly, a direct channel through GDP growth rate and an indirect channel from firms' total assets growth rate.

- Operating expenses growth rate

$$\%\Delta OpEx_s^{i,t} = \beta_0 + \beta_1 \%\Delta Revenues_s^{i,t} + \beta_2 t + \varepsilon_s^{i,t} \quad (4)$$

Operating expenses capture what proportion of the increase in revenues are translated to operating expenses. Annual changes in carbon prices and energy prices are captured in the production costs of firms.

- Total assets growth rate

$$\%\Delta TA_s^{i,t} = \beta_0 + \beta_1 \%\Delta GDP_s^t + \beta_2 t + \varepsilon_s^{i,t} \tag{5}$$

where we include time dummies as control variables. The total assets equation captures how differences in GDP growth rate from climate policies impacts firms' total assets growth rate.

- Leverage

$$Leverage_s^{i,t} = \frac{Total\ debt_s^{i,t}}{Total\ assets_s^{i,t}} \tag{6}$$

Leverage is defined as firms' total debt over total assets.

- Output gap

$$Outputgap_s^t = \frac{(Actual\ GDP\ output_s^t - Potential\ GDP\ output_s^t)}{Potential\ GDP\ output_s^t} \tag{7}$$

Output gap is defined as the difference between the actual output of an economy and its potential output divided by its potential output.

- Probability of default

$$PD_s^{i,t} = \beta_0 + \beta_1 Profit_s^{i,t} + \beta_2 Lev_s^{i,t} + \beta_3 Output\ gap_s^t + \beta_4 \log\left(TA_s^{i,t}\right) + \beta_5 sector^i + \varepsilon_s^{i,t} \tag{8}$$

The model estimates the relationship of probability of default with the firm's profitability and leverage ratio as well as other macro and firm level variables. Logarithmic of firm's total assets are used to control for size effect. Observations on annual PDs were obtained from Bloomberg.

The estimation results for equations (3) – (6) and (8) are presented in Annex C.

Projection block

Each estimated equation described in the estimation block is projected iteratively for each forecast year based on NGFS scenarios. The following are the key steps used at the projection stage to derive the projected PD for each firm:

- Revenues

$$Revenues_s^{i,t} = Revenues_s^{i,t-1}(1 + \%\Delta Revenues_s^{i,t}) \quad (9)$$

Revenue for each forecast year is projected by the estimate $\%\Delta Revenues_s^{i,t}$ derived from equation (3).

- Operating expenses

Operating expenses are projected in two stages.

(a) Firstly, operating expenses follow the projection of equation (4).

$$\widehat{OpEx}_s^{i,t} = OpEx_s^{i,t-1}(1 + \%\Delta OpEx_s^{i,t}) \quad (10)$$

(b) The second step further incorporates carbon cost and energy cost that arise from different NGFS scenarios into the calculation of operating expenses.

$$OpEx_s^{i,t} = \widehat{OpEx}_s^{i,t} + \Delta cost(carbon\ cost_s^{i,t}) + \Delta cost(energy\ cost_s^{i,t}) \quad (11)$$

where

$$\Delta cost(carbon\ cost_s^{i,t}) = carbon\ tax_s^{i,t} * Scope1_s^{i,t} - carbon\ tax_s^{i,t-1} * Scope1_s^{i,t-1} \quad (12)$$

and

$$\Delta cost(energy\ cost_s^{i,t}) = energy\ price_s^{i,t} * energy\ consumption_s^{i,t} - energy\ price_s^{i,t-1} * energy\ consumption_s^{i,t-1} \quad (13)$$

where carbon cost is a function of the firm's Scope 1 emission and the price of carbon tax under different scenarios. Moreover, the firm's Scope 1 emission depends on the firm's revenue and changes across time and scenarios. Energy cost is a function of the firm's energy price and energy consumption. Specifically, energy price and energy consumption are calculated using a function of energy mix and the firm's Scope 2 emission under different scenarios.

- Total assets

$$TA_s^{i,t} = TA_s^{i,t-1}(1 + \%\Delta TA_s^{i,t}) \tag{14}$$

Total assets for each forecast year is projected by the estimate $\%\Delta TA_s^{i,t}$ derived from equation (5).

Based on the projected estimates of revenue, operating expenses and total assets described above, firm's profitability is then projected in accordance with equation (1).

- Leverage

In order to project a firm's leverage ratio, we have to first project total debt and then include investment cost for developing green technology. The steps are as follows.

(a) In our model, we assume that the capital structure ratio, namely asset, liability and equity, will remain constant overtime. Under this assumption, total debt follows the growth path of total assets.

(b) In addition to total debt, leverage also accounts for the cumulative increase in debt from the previous and current additional investment made by firms to develop greener technologies to meet their emission targets under different scenarios.

$$Additional\ Investment_s^{i,t} = \Delta(Total\ Emissions)_s^{i,t}\left({}^{t}/_{CO2}\right) * replacement\ cost_s^{i,t}\left(\frac{\$}{{}^{t}/_{CO2}}\right) \tag{15}$$

$$Investment_s^{i,t} = \sum_{t=0}^{T}(\ Additional\ Investment_s^{i,t}) \tag{16}$$

The amount of additional investment needed is a function of the decrease in emissions firms have to make, which in turn depends on firms' revenue, and replacement cost that differ across different scenarios. In our model, while firms are assumed to invest in green technology for the Net Zero 2050, Below 2 °C and Delayed transition scenarios, for the Current policies scenario, firms are not assumed to invest in green technology, as the transition to a green economy does not take place and emissions are achieved thanks to policies and technology already in place before the start of the scenario horizon.

Combining these two effects, we can project leverage as follows:

$$Leverage_s^{i,t} = \frac{Total\ debt_s^{i,t} + Investment_s^{i,t}}{Total\ assets_s^{i,t}} \tag{17}$$

Given the projected profitability and leverage and output gap derived from above, firms' PD would then be projected by plugging these estimates into equation (8).

Annex C: Estimation results

Table A2

Estimation of firm equations

VARIABLES	(1) %Δ TA	(2) %Δ Rev	(3) %Δ OpEx
%Δ GDP	0.385***	0.302***	
	(0.0363)	(0.0436)	
%Δ TA		0.350***	
%Δ Rev			0.648***
			(0.0103)
Constant	0.0136***	0.00555	0.00699
	(0.00339)	(0.00403)	(0.00535)
Observations	10,587	7,298	7,591
Adjusted R-squared	0.0772	0.133	0.436
Time dummies	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Notes: The data is winsorised to reduce the influence of extreme values on the precision of the estimates.

Table A3

Estimation of Probabilities of default

VARIABLES	(1) PD
Leverage	0.0660***
	(0.00208)
Profitability	-0.0697***
	(0.00270)
GDP gap	-0.269***
	(0.0241)
Log TA	-0.00506***
	(0.000133)
Constant	0.122***
	(0.00309)
Observations	29,199
Adjusted R-squared	0.225
Sector dummies	YES
Time dummies	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Notes: The data is winsorised to reduce the influence of extreme values on the precision of the estimates