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CLIMATE STRESS TEST BRIEFING NOTE

COMMENTS ON THE REVISED ECB CLIMATE STRESS TEST APPROACH [1] [2]

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1. Overview:

In a pair of recent Occasional Studies released in 2021 and September 2023, the European Central Bank (ECB) presented results from its approach to climate stress testing. Drawing on scenarios from the global NGFS consortium and data on emissions, geolocation, and company financial reports, the ECB's approach combines 'top-down' macroeconomic and carbon-mitigation scenarios with firm-level financial models. These studies have contributed to ongoing discussions of climate-change effects on financial stability and are influencing banks in their own climate-modelling efforts, which are at an early stage. Many observers anticipate that regulators will call for banks to have some kind of initial climate-stress-test approach in place by the end of 2024. Climate modelling to assess credit risk stress impacts is currently hindered by the sparseness of empirical evidence demonstrating a link between climate metrics such as Global Mean Temperatures ('GMT') and credit- and market risk measures.[3]

The 2023 paper (ECB, 2023) focuses more narrowly on transition risk, not both transition and physical risk as the earlier 2021 ECB paper did and includes more detail on the projected energy transition for Europe. Our comments in this note focus on the cost-passthrough and financing assumptions driving the results and the sharp differences in credit impacts estimated in the 2021 study compared to the 2023 study. We highlight the substantial differences in PD impacts, since many banks are currently working on similar models estimating the credit impacts of climate change.

To summarise, the two models:

- assume *unconventional cost passthrough assumptions:* costs of transition to lower emissions and (additionally in the first paper of physical damage due to more frequent extreme weather events) *are not fully recovered in revenues* and that

[1] This ZRE Briefing Note provides preliminary commentary on the evolving ECB Climate Stress Test Methodology - feedback and comments welcome, any errors or omissions remain the responsibility of the authors.
[2] We review the ECB climate stress test methodology by comparing the approaches and the resulting firm-level credit model (PD) impacts in the two most recent ECB methodology papers (Algoskoufis, et. al. 2021) referred to as ECB 2021 and (Emambakhsh et. al. 2023), referred to as ECB 2023.
[3] See, Aguais and Forest (2023, b) for a discussion related to assessing the statistical relationship between rising GMT trends and measures of economic risks (volatility).

financing of green investments *involves only debt*, not the usual mix of equity and debt, and

- find, therefore, that climate-related transition and physical damage cause *profitability to drop, leverage to rise*, and probabilities of default (PDs) to increase for the median firm.

If one were instead to assume near full recovery of cost increases consistent with most long-run analyses and use of the customary mix of debt and equity in green investments, arguably the credit impacts on the median firm would be very small. [4]

Additionally, the more recent model obtains credit impacts much larger than those from the earlier 2021 model for reasons that are not entirely clear. One might have expected the reverse, since the more recent results consider only transition costs over a shorter horizon of 2022-2030, whereas the earlier ones include both transition costs and physical damage over 2020-2050. Evidently, the estimates of the magnitudes of cost increases, the amounts of green investments, and the effects of those things on profitability, leverage, and PDs are much larger in the second study. [5]

2. Both Studies Obtain Credit Impacts Through Implausible Cost Passthrough and Financing Assumptions:

In a pair of Occasional Studies released in 2021 and September 2023, the ECB introduced models providing estimates of the credit impacts from climate-change. The earlier study estimates the impacts of both physical damage and transition over 2020-2050, whereas the latter estimates only transition impacts over 2022-2030. Both the earlier and especially the latter estimates, which indicate *orders-of-magnitude larger impacts*, reflect implausible cost passthrough and financing assumptions. Indeed, the studies assume no passthrough of projected rises in the costs of brown energy and electric power and 100% debt financing of green investments.

Assuming more conventionally mostly full proportional passthrough of overall-average cost increases and the use of the customary debt-equity mix in financing of green investments, it seems likely that the aggregate credit impacts would be substantially smaller. Of course, firms with above average cost rises would suffer decreasing output shares, declining margins, and increasing default rates, while those with below average cost rises would enjoy

[4] More realistic assumptions would lead to smaller suggested direct PD impacts on firms. However, in general, current climate risk modeling and this research by the ECB broadly excludes uncertainty related to the systematic impacts of future climate/credit risk shocks. Future climate risks are subject to substantial uncertainty including from the potential for rising volatility driven by increasingly severe weather, and major carbon policy and socio-economic shocks. In Aguais and Forest (2023, a) we highlighted the fact that rising volatility may be a key driver adding risk and uncertainty to the types of direct PD effects outlined in the ECB climate papers.

[5] The broad cost pass-through and financing assumptions between the two models are similar. Therefore, one of the potential reasons for finding much larger PD impacts in 2023 that are not fully explained, may relate to the underlying PD credit model specification and calibration along with other misc. assumptions also not fully explained.

mostly the opposite circumstances. On balance, however, it seems likely with assumptions consistent with the past, that these countervailing effects could mostly offset each other. Under several climate policy scenarios, firms would generally see accelerated retirement of legacy brown assets. One of the primary questions in climate-credit modelling therefore is how these carbon mitigation policies are phased -in. Implementation of smoother, well-articulated carbon mitigation policies would lead to smoother ‘brown’ energy asset retirements, with broad-based depreciation rates being priced into products. Under this type of assumption, the aggregate credit impacts would likely be small. In contrast large carbon policy ‘shocks’ would suggest larger credit impacts.

3. 2023 ECB Study Estimates Credit Impacts Much Larger than Those in the Earlier 2021 Study:

The most recent 2023 ECB projections indicate that climate transitions consistent with a 1.5° temperature anomaly in 2050 cause the probability of default (PD) of a median corporate bank loan over 2022-30 to rise by as much 100- percent, compared with the roughly 25 percent rise expected in an NGFS *Current Policies* baseline scenario that involves no expanded policy initiatives for transition (**Table *1***). [6] [7] These results are strikingly different from the 2021 ECB study estimates, which show essentially no PD rises over 2020-2030 and at most roughly 6 percent over 2020-2050. [8] For descriptions of the various scenarios in the two studies see **Table 2**.

The earlier 2021 study includes both physical and transition impacts and the more recent one only transition costs. Thus, one has trouble understanding the greater magnitudes of the PD impacts shown in the more recent study. Further, since the *Hot House* scenario in ECB 2021 closely resembles the *Current Policies* scenario in the 2023 study, we see that the new estimates reverse the relative PD changes reported in the 2021 study. Thus, in the earlier study, the *Hot House* scenario has PD changes larger than in the *Orderly Transition* and *Delayed Transition* scenarios. But in the more recent study, the *Current Policies* scenario, which closely resembles the earlier *Hot House* one, has the smallest PD changes, below those in the *Accelerated Transition, Delayed Transition*, and *Late Push Transition* scenarios.

The two studies do not offer a transparent explanation of these striking differences. Evidently, the estimates of the magnitudes of cost increases, the amounts of green investments, and the effects of those things on profitability, leverage, and PDs are much larger in the second study.

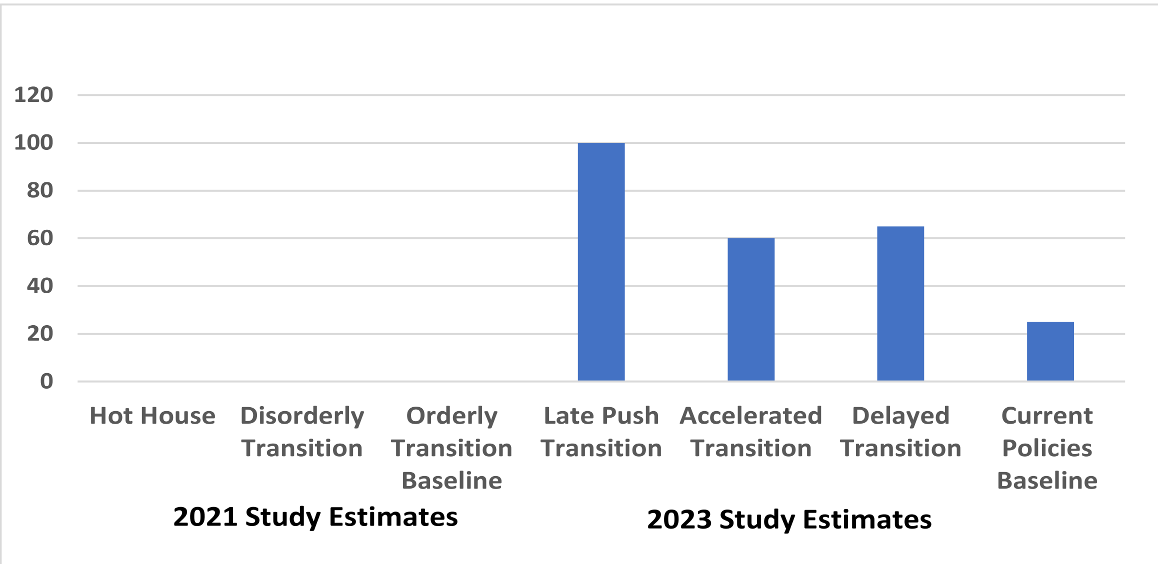
[6] The analysis of PD impacts we discuss here from the two ECB papers has been developed through various results presented in the text discussion and approximations read from various ECB figures.
[7] See ECB 2023 pages, 57-64.
[8] See ECB (2021) page, 54.

Table 1: Median Percentage Changes in Bank Corporate Loan PDs in Various Scenarios[1]

Study Date	Scenario	Base Year	% Change from Base Year	
			2030	**2050**
2021	*Hot House*	2020	0.0	6.0
	Disorderly Transition		0.0	1.0
	Orderly Transition Baseline		0.0	-2.0
2023	*Late Push Transition*	2022	100.0	NA
	Accelerated Transition		60.0	NA
	Delayed Transition		65.0	NA
	Current Policies Baseline[2]		25.0	NA

*[1]**Approximate values** from text discussions and **read from graphical displays.***
*[2] **Based on** PDs derived from credit loss estimates assuming fixed LGD and EAD values**.***
Sources: ECB 2021 and ECB 2023.

Figure 1: Estimates of Percentage Median PD Changes from the Base Year to 2030[1]



[1] Base year is 2020 in the 2021 study and 2022 in the 2023 study.
Sources: ECB 2021, and ECB 2023.

Table 2: Climate Scenarios in the ECB Studies:

Study Date	Scenario	Scenario Description
2023	*Late Push Transition*	Transition starts in 2026 but, due to late push, achieves emissions reductions in 2030 consistent with a path toward 1.5° target for 2100

	Accelerated Transition	Transition starts in 2023 and achieves emissions reductions in 2030 consistent with a path toward 1.5° target for 2100
	Delayed Transition	Transition starts 2026 but less aggressive policies achieve emissions reductions in 2030 consistent with a path toward 2° target for 2100
	Current Policies Baseline	No transition policies other than those already in place and so has emission reductions in 2030 consistent with a path toward at least 3° target for 2100
2021	*Hot House*	No transition policies other than those already in place and so emission reductions in 2050 consistent with at least 3° target for 2100
	Disorderly Transition	Climate measures delayed and more abrupt than in the baseline below but still with emissions reductions in 2050 consistent with a below 2° target for 2100.
	Orderly Transition Baseline	Climate measures well calibrated and timely and consistent with emissions reductions in 2050 consistent with a below 2° target for 2100.

Sources, ECB (2021) and ECB (2023).

4. ECB PD Model Formulas Document Implausible Cost Passthrough and Financing Assumptions:

Both sets of estimates and particularly the most recent 2023 ones reflect implausible cost passthrough and financing assumptions. Under more conventional assumptions, the PD effects in the aggregate as measured by medians or means would largely be reduced. But one might still find substantial cross-company effects, in which firms with above-market-average exposures to climate-change impacts would endure decreases in creditworthiness and firms with below-market-average exposures would experience increases.

Here we highlight key aspects of how the ECB climate-adjusted PD approach implements key assumptions for cost passthrough and financing. Understanding the ECB formulation of key climate assumptions in PD models can *help inform bank's own climate PD model development. Developing a flexible capability for assessing a wide range of climate modelling assumptions is key to support climate model sensitivity analysis.*

The 2023 ECB model's earnings projections for firms assume full passthrough of cost markups into prices and revenues of other cost increases but no passthrough at all of increases in brown-energy and electricity costs. We see this in the formulas (1) below adapted from A2.4, A2.5, and A2.6 in the 2023 ECB study.[9]

$$\begin{aligned} &Revenues(t) && = Assets(t) \cdot Revenues(0)/Assets(0) \\ &Operating\ Costs(t) && = Assets(t) \cdot Operating\ Costs(0)/Assets(0) \\ & && \quad + \Delta Brown\ Energy\ Costs(t) + \Delta Electricity\ Costs(t) \\ &Operating\ Earnings(t) && = Revenues(t) - Operating\ Costs(t) \end{aligned} \tag{1}$$

[9] See, Emambakhsh et. al., (2023) pages 88-89.

Increases in brown-energy and electricity costs push up operating costs, but not revenues. As a result, operating earnings drop relative to revenues and assets. The asset projections involved in the revenue and cost estimates for various climate scenarios come from NGFS forecasts of gross value added and inflation.

Within energy sectors the projections further assume that, without associated cost changes, revenue drops for brown (e.g., oil and gas) products and increases for green. *The revenue shifts seem plausible, but not the magnitudes of the implied profit shifts.*

The model assumes that, while other investments involve the past mix of debt and equity, green investments are 100% debt financed. We see this below in formulas (2) adapted from A2.7 and A2.14 in ECB (2023). [10]

$$\begin{aligned} Total\ Liabilities(t) \quad &= Total\ Liabilities(0)/Assets(0) \cdot Assets(t) \\ &+ Green\ Investments(t) \\ Leverage\ (t) \quad &= Total\ Liabilities(t)/Assets(t) \end{aligned} \tag{2}$$

Cumulative green investments since the base year raise liabilities but not assets. Thus, green investments increase leverage.

The pretax earnings projections arise from deducting amortization and finance expenses from operating earnings. We see this below in formulas (3) for pretax earnings and profitability adapted from A2.10. and A2.13 in ECB (2023). [11]

$$\begin{aligned} Net\ Earnings\ Before\ Tax(t) \quad &= Operating\ Earnings\ (t) - Amortization(t) \\ &- Financing\ charges\ (t) \\ Profitability(t) \quad &= Net\ Earnings\ Before\ Tax(t)/Assets(t) \end{aligned} \tag{3}$$

The 2023 ECB annex text explains that green investments increase amortization and finance charges and so reduce pretax earnings and profitability. Again, we see no passthrough of those costs.

Finally, we get the logit PD function below in which the ECB model involves different calibrations for each of eight segments with heavily energy-intensive sectors split out. The formula (4) below translates the log-odds relationship at A2.2 into a PD function.[12]

$$PD(t) = \frac{exp(a + b \cdot Profitabiity(t) + c \cdot Leverage(t))}{1 + exp(a + b \cdot Profitabiity(t) + c \cdot Leverage(t))} \tag{4}$$

The calibration of this 2023 model used default/nondefault events inferred from financial information on a large sample of companies in the Orbis database.

[10] See, Emambakhsh et. al., (2023) pages 89, 91.
[11] See, Emambakhsh et. al., (2023) pages 90, 91.
[12] See, Emambakhsh et. al., (2023) page 86.

Overstated profitability declines and leverage increases lead to the suggested substantial PD rises in the 2023 approach. In the case of no change in profitability and leverage of the median firms in each market, the median PDs would remain unchanged.

5. Earlier ECB 2021 Model Includes Physical Damage and Carbon Tax:

Further comparing the two approaches focusing on the earlier 2021 ECB model in comparison to the 2023 ECB model, the 2021 model:

- covered both physical damage as well as transition effects on credit risk,
- included a negative effect on business revenues of carbon taxes, and
- defined profitability affecting PDs as earnings before rather than after amortization and finance expenses and so excludes any effects of green investments on those charges.

For 2021 as in the later 2023 model, costs rise relative to revenues due to Climate-related carbon and energy cost increases. And differently for the 2021 study, costs rise relative to revenues due to property-and-casualty-insurance cost increases and revenues fall relative to costs due to uninsured physical-asset damage and VAT tax hikes. We see these effects in the formulas (5) below adapted from equations (2), (3), and (4) in ECB 2021.[13] The 2021 model treats prospective carbon-tax rises as having revenue effects equivalent to past VAT rate increases.[14]

$$
\begin{aligned}
Revenues(t) \quad & = a_0 + a_1 Revenues(t-1) \\
& + a_2(Assets(t) - UncoveredDamage(t)) \\
& + a_3 VAT(t) + a_4 t + a_5 SectorDummy \\
Operating\ Costs(t) \quad & = b_0 + b_1 Operating\ Costs(t-1) + b_2 Assets(t) \\
& + b_3 t + b_4 SectorDummy \\
& + \Delta CarbonCost(t) + \Delta EnergyCost(t) \\
& + DamageInsuranceCost(t) \\
Operating\ Earnings(t) \quad & = Revenues(t) - Operating\ Costs(t) \\
Profitabilitu(t) \quad & = Operating\ Earinings(t)/Assets(t)
\end{aligned}
\tag{5}
$$

Leverage in the 2021 projections increases due to the cumulative amounts of green investments and replacement of damaged assets, with both of those items assumed to be financed entirely through debt.

$$
\begin{aligned}
Leverage(t) \quad & = Historical\ Leverage \\
& + \frac{Green\ Investments(t) + Uninsured\ Damage(t)}{Assets(t)}
\end{aligned}
\tag{6}
$$

[13] See, Algoskoufis et. al., (2021) page 79.

[14] See, Algoskoufis et. al. (2021, Appendix B: analytic steps, pp79-85.

Profitability and leverage enter as explanatory variables in the PD model. The PD model in the earlier 2021 model evidently was a linear one. [15] The formula in the document was linear and the text did not indicate any transformation of that formula. The PD model in ECB 2021 was calibrated to Moody's CreditEdge EDFs.

Despite the expanded number of ways in which climate effects diminish profit margins, the earlier 2021 model projects much smaller Climate-related credit impacts compared to 2023. Evidently, subtle features in the ECB 2023 study such as the calibration of the revenue, cost, and PD formulas and determination of the sizes of the cost and financing effects account for these much larger effects.

6. Accelerated Retirement of Brown Assets Could Raise PDs for Some Firms:

In general, accelerated retirement of brown assets could raise the PDs of firms with above average shares of such assets. Elevated rates of retirement would raise costs relative to revenues. If firms with an average share of brown assets in a market represent the marginal producers and thus influence prices, then those with above average shares and higher costs relative to revenue would have increased PDs. Those with below average shares would have potentially decreased PDs. Over time, all firms would have diminishing shares of brown assets.

If the retirement rates rise gradually due to a transparent phase-in of policies promoting this, then the PD impacts would likely be small. Under a sharp sudden rise in retirements, driven by substantial policy shocks, the impacts would be larger. However, as a rule, to avoid unduly adverse effects, policies of this sort are usually made clear, and phased in. However, climate change is driven by substantial uncertainty in many forms, therefore substantial complex, sudden changes (shocks) relative to current climate policies could lead to large economic and credit impacts.

This might explain some of the ECB model's estimates of PD rises. The 2023 study documentation based on our preliminary review, however, does not explicitly identify accelerated or volatile carbon asset retirements as the main cause of the estimated PD increases.

7. Lessons from Both ECB Model Approaches for Bank Credit Model Development:

Building on the ECB contributions, a flexible climate-adjusted modelling approach would allow for different possible amounts of passthrough into revenues of the cost rises attributable to transition to lower emissions and to increases in physical damage from such things as rising sea levels and more extreme weather tied to climate change. The ECB estimates involve extreme assumptions that very likely give rise to upwardly biased estimates of impacts. At the other extreme, one could assume full passthrough of the costs

[15] See, Algoskoufis et. al., (2021) page 80, equation 7.

by the median firm, and the aggregate impacts would be quite small. In this second case, one would be left mainly with relative impacts, with firms experiencing above average cost increases compared with their peers enduring falling profitability, increasing leverage, and rising PDs and those with below average increases enjoying falling PDs.

One might also want to distinguish between expected long-run cost increases, with firms adjusting to those changes, and unexpected short-run cost shocks, which provide limited opportunity for adjustment. The former would involve close to full passthrough and have only minor impacts on credit risk, whereas the latter would have much larger impacts. In this latter case, one might need to introduce a model in which such cost and other shocks occur stochastically, with no warning.

The suggested effects focused on direct firm-level climate impacts, exclude the potential for broader systematic effects (sector/region) of future credit/climate shocks of all kinds. Credit markets have clearly been shown to be subject to periodic, large systematic volatility from several types of credit shocks as in 2007/08. As our recent climate research has highlighted, future climate related shocks will potentially add to the systematic volatility in credit losses observed historically.

Therefore, a full climate risk stress test framework would integrate both company-specific climate effects like those outlined in the ECB research and the application of climate-sensitive systematic credit factors.[16]

8. Summary

This briefing note provides initial commentary on the evolving ECB Climate Stress Test approach, documented in detail in a September 2023 ECB paper. The ECB continues its substantial climate research effort to develop an overall framework that banks can use as guidance for their own climate stress test preparation to develop internal climate-adjusted credit models, initially for PD for wholesale borrowers.

Climate stress test modelling in general remains a work-in-process, with this 2023 ECB paper building on the ECB research published in 2021. In this note we have highlighted two key aspects of the ECB's ongoing climate/credit risk research that:

(1) The *core assumptions* applied by the ECB for energy cost passthrough and green financing, which are similar in both the 2021 and 2023 papers remain *unconventional* relative to observed historical experience. These include zero cost

[16] See Aguais and Forest (2023, a, d) for how systematic credit factor models can be adapted to assess future climate volatility and shocks and how company level climate models similar to the ECB approach, can be fully integrated with portfolio credit factor models assessing systematic credit/climate impacts. Aguais and Forest (2023, d) proposes a direct approach we refer to as company-level 'TTC Drift' where firm-level PD impacts from company climate-adjusted PD models are integrated directly with the ZRE systematic 'Z' credit factors. Our forthcoming Oxford Centre for Greening Finance and Investment ('CGFI') paper will present this integrated company/sector/region approach in detail.

passthrough of future energy cost changes and 100% debt financing of future green investments.

(2) The 2023 ECB paper while shifting focus to primarily transition risk from both physical and transition risk in the 2021 paper, finds over a shorter time horizon to 2030, *substantially larger climate impacts on wholesale PDs*.

The ECB climate stress test research is designed to support a key ECB Supervisory Objective for 2022-24 focused on 'tackling emerging risks, including Climate-related and environmental risks' which are described in detail in ECB (2022).

In this note we have highlighted the key assumptions and substantial changes in climate PD impacts across the two recent ECB research papers. Overall, in our opinion, it is key for banks and regulators to continue their climate model development activities while also moving toward a common overall approach to assess potential, future climate credit risk impacts because these models remain a work-in-process. Current climate research is quickly moving toward more specific stress test requirements for banks while at the same time there is limited data to develop climate models. Wide divergence also remains in the core modelling assumptions applied and current climate modelling suggests widely divergent potential impacts.

Overall, it behoves banks to continue their own climate/credit research and modelling efforts to support more active dialogue with regulators on this complex topic of climate risk modelling. This is because no current, broad consensus exists to specify an overall climate stress scenario framework. The wide divergence in PD effects pointed out in this note between the two recent ECB studies is indicative of the lack of any core consensus on climate modelling.

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