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Stress testing a China hard landing

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EXECUTIVE SUMMARY

The decline in Chinese equities and commodity prices this summer renewed investor concerns about a possible economic hard landing in the Asian giant. In particular, the 8.5% market plunge on 24 August (China Black Monday) spread fear into global markets that continues to this time.

As global economic and market uncertainty persists, a coherent and a structured approach to assess macroeconomic and market scenarios and their impact on investor portfolios is essential. This paper demonstrates that investors can use a carefully designed stress test to quantify the potential impact of a China hard landing on global multi-asset class portfolios, combining the MSCI Macroeconomic Risk Model with RiskManager's predictive stress testing capabilities.

The first step in systematically evaluating a macroeconomic scenario is to define the baseline. According to the MSCI Macroeconomic Risk Model baseline, China's economy could grow by 7.1% over the next year. Hard landing is defined as a sharp drop in Chinese real GDP growth of 5.2 percentage points to about 2% – the equivalent of a two-standard deviation event relative to the baseline.

Investors' beliefs about the evolution of economic and market trends, including possible contagion effects, were then modeled. This step can be formalised within the modeling framework. More precisely, economic contagion in the model is driven by the trade linkages specific to each pair of countries. The prevailing bilateral trade-weights help define a medium contagion scenario, reflecting that China's economy is still not fully integrated with the rest of the world. However, in times of market turmoil, investors could perceive that the Chinese economy is more integrated with the global economy than it actually is, resulting in investor overreaction and greater contagion effects. Therefore, a high contagion scenario is also defined, that reflects investors' beliefs that the Chinese economy is as integrated as the US economy.

Finally, the effects of these scenarios are traced to asset returns. The findings indicate that the prospect of an economic hard landing in China may significantly impact Chinese, Emerging and Japanese equity markets. However, the impact on a global multi-asset class portfolio could depend on the investors' perception of China's economic integration with the rest of the world. While the portfolio might lose only 3% under the medium contagion

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scenario, the impact could be a more severe decline of 8.4% under the high contagion scenario.

1. A COHERENT STRESS TESTING FRAMEWORK

The first step in designing a coherent stress test for a China hard landing is to define the baseline scenario. The baseline sets bands against which the stressed scenario can be measured. The MSCI Macroeconomic Risk Model[1] can be used to define such a baseline scenario, as well as provide confidence bands around the baseline. For example, according to the model, China's economy could grow by 7.1% over the next year. A hard landing is defined as a sharp drop in Chinese real GDP growth of 5.2 percentage points to about 2%. Such a precipitous decline would be the equivalent of a two-standard deviation event relative to the baseline.

Next, we modeled investors' beliefs about the evolution of economic and market trends, including the perception of possible economic contagion effects. This step can be formalised within MSCI's flexible modeling framework. More precisely, the trade linkages specific to each pair of countries are the key drivers of the degree of economic contagion in our globally integrated model. The prevailing bilateral trade-weights reflect that China's economy is still not fully integrated with the rest of the world and help define a medium contagion scenario. However, during periods of market turmoil, investors could perceive greater integration than actually exists and overreact. In this high contagion scenario, investors believe the Chinese economy is as integrated as the US economy.

As a third step, a parsimonious set of core market risk factors is selected that are:

- Likely to be causally related to the transmission of a Chinese economic slowdown to the financial markets; and,
- Relevant to the portfolio to which the stress test will be applied.

The Macroeconomic Risk Model is then used to trace the effects of the China hard landing scenario to the set of core market risk factors.

Finally, the shocks of the parsimonious set of core market risk factors are propagated to all other risk factor and portfolio returns. For this step, MSCI RiskManagers predictive stress test tool is used. A set of best practice guidelines was adhered to, in order to reduce the prediction error in the propagation step. The predictive stress test was vallidated with a set of quantitative stress test diagnostics.

This paper applies the framework described above in order to design a coherent China hard landing stress test for a globally diversified multi-asset class portfolio. In particular, a portfolio's specific characteristics could dictate a different choice of core market risk factors.

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For example, the core market risk factors could be aligned with the portfolio's specific country tilts.

2. A HARD LANDING SCENARIO WITH MEDIUM CONTAGION

Despite concerns underpinning the China Black Monday, Chinese industrial production and retail sales have continued to improve over the past year. Consistent with these trends, the Macroeconomic Risk Model's baseline scenario (Figure 1) is for the Chinese economy to grow at a rate of 7.1% over the next 12 months. This growth rate is lower than the long-term trend through 2007, but is still steady.

However, Chinese equity and commodity prices have declined significantly through the summer, and investors' fears of a possible sharp slowdown in Chinese real economic activity could have been compounded by the delayed response from the Chinese authorities. These fears could have been further exacerbated by the prospect of an early rise in US interest rates – with its potentially adverse consequences for US and emerging market economies.

As discussed in the previous section, to simulate a possible scenario of China hard landing, GDP growth over the next year is assumed to decline by 5.2 percentage points from the baseline scenario of 7.1%, resulting in Chinese real GDP growth of only around 2%. This hypothetical drop in the Chinese growth rate is the equivalent of a two-standard deviation change, as measured by the MSCI Macroeconomic Risk Model.

In the remainder of this section, the impact of this scenario on selected equity, interest rate, credit, commodity and volatility risk factors is estimated. These core risk factors will then be used to assess the potential impact of the scenario on all market risk factors and a hypothetical multi-asset class portfolio.

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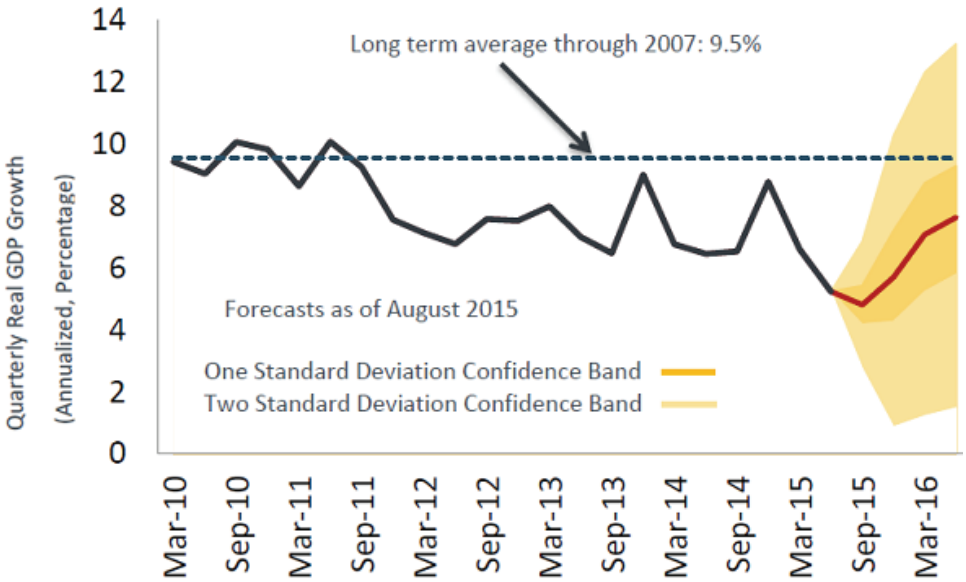
Figure 1: Quarterly Chinese Real GDP Growth



Source: MSCI. Note: After dropping sharply in early 2008, the Chinese quarterly real GDP growth rate (black line) spiked, only to decline gradually during the last five years. The MSCI Macroeconomic Model projects rates for the next four quarters ending June 2016 (red line), providing 30-70 and 5-95 confidence bands. All growth rates are annualized percentage rates.

2.1 Equities, Bonds and Credit

To start, the Macroeconomic Risk Model is applied to assess the impact of the hard landing scenario on selected equity, government bond and credit market risk factors.

The global integrated model first propagates the impact of the Chinese growth shock (-5.2 percentage points) to other countries' growth, taking into account China's trade linkages with the rest of the world. As shown in Figure 2, a hard landing in China could have a pronounced economic impact on Japan, as well as China's key emerging market trade partners. However, the impacts on the US and other developed market economies could be more muted, reflecting China's relatively immature level of global economic integration.

For each country, the model quantifies the impact of economic growth shocks on equity market dividends and the government bond discount factor (yield curves) over multiple horizons, arriving at the expected impact on asset value through a discounted cash-flow calculation. The impact on the selected equity market index values, relative to the model's baseline scenario (no shocks) is as follows:[2]

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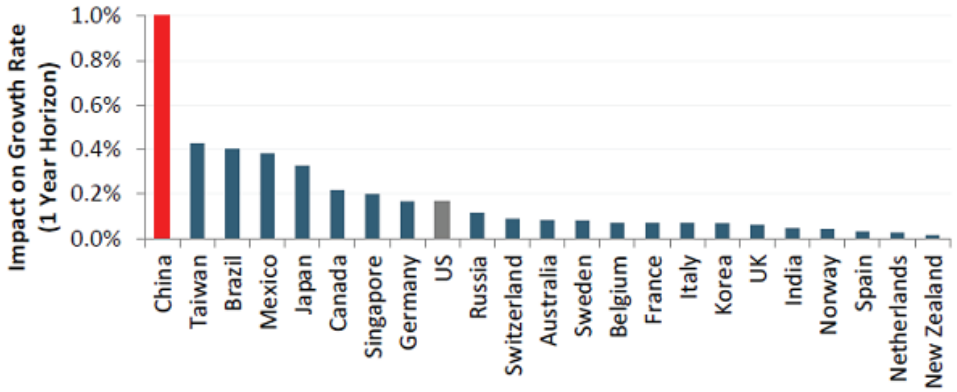
- MSCI China: -25%
- MSCI Japan: -9%
- MSCI Emerging Markets: -12%
- MSCI ACWI + Frontier Markets: -4.8%

The model also provides the impact of the hard landing scenario on US, Japanese 10-Year treasury yields and the 10-Year U.S. BBB corporate bond yield, relative to the model's baseline scenario:

- US Government 10Y: -17bps
- Japan Government 10Y: -10bps
- US BBB 10Y: -5bps

Changes in equity prices primarily reflect long-term cash flow exposures to real GDP growth uncertainty. As a result, the perception of an economic hard landing in China could significantly impact Chinese, Emerging and Japanese equity markets, consistent with what was observed during the week of 24 August. However, also consistent with our observation, the impact on other developed economies' equity, bond and credit markets could be muted, reflecting the fact that China's economic and financial integration with the rest of the world is still maturing.

Figure 2: Medium Contagion Scenario: Impact of a 100 bps Shock to Chinese Real GDP Growth



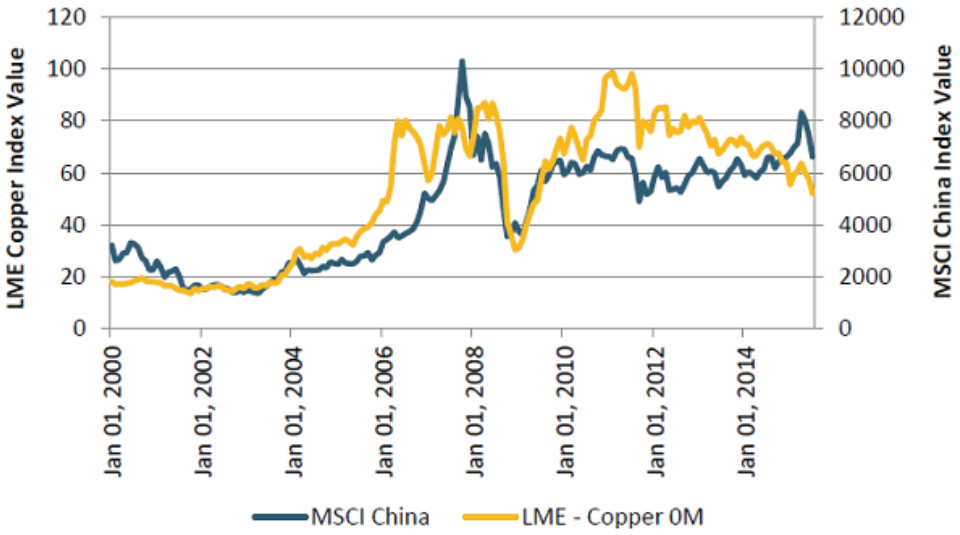
Source: MSCI

2.2 Commodities

A China hard landing, however, could significantly impact commodity markets. As commodities are not yet part of the Macroeconomic Risk Model, a separate analysis is performed to estimate the sensitivity of commodities to Chinese equities.

In the China hard landing hypothetical stress test, copper is used as a core factor to represent commodity markets. Chinese economic growth has been the primary driver of copper prices in the last 15 years, and copper prices are highly correlated to Chinese equity markets. Figure 3 reveals the potential strength of this relationship, especially following sharp economic downturns such as that in 2008. Figure 4 shows a scatter plot of the monthly returns to the MSCI China Index[3] and the copper price. A regression of the copper price onto the MSCI China Index using monthly returns between 2000 and 2015 yields a beta coefficient of 0.44, with an R-squared of 20%. Based on the output from the Macroeconomic Risk Model, which assigns a return to MSCI China of -25%, and the sensitivity estimated by the regression model, copper prices could decline by 11% under the hard landing scenario.

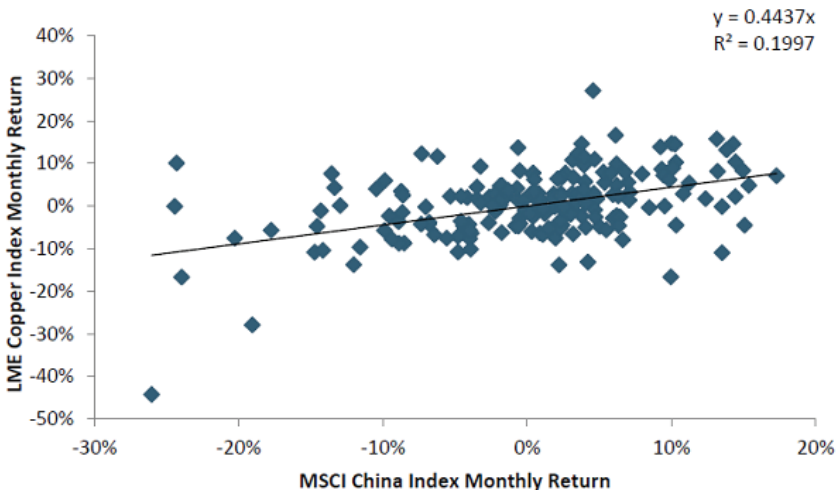
Figure 3: Relationship between the MSCI China Index and the LME Copper Index Value



Source: MSCI

Figure 4: Sensitivity of Copper to Chinese Equities

Monthly returns between 2000 and 2015



Source: MSCI

2.3 Market volatility in a hard landing

Market turbulence is reflected by applying a shock on the VIX index equal to an increase of 25%, which is roughly a one-sigma shock in terms of a bi-weekly return horizon. The full scenario, which combines the equity, interest rate, commodity and volatility shocks, is summarised in Figure 5.[4]

Figure 5: Core Risk Factor Shocks in the Medium Contagion Scenario

Core Risk Factor	Medium Contagion Scenario Shock
MSCI Japan	-9%
MSCI EM	-12%
MSCI ACWI + FM	-4.8%
MSCI China A + B + H	-25%
USD Govt 10Y	-17bps
JPY Govt 10Y	-10bps
USD All Sectors BBB 10Y	-5bps
LME Copper 0M	-11%
VIX	+25%

Source: MSCI Note: The risk factor related to credit instruments is the USD All Sectors BBB 10Y interest rate, which drops by 5bps. This corresponds to a widening in credit spreads of 12bps

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3. A HARD LANDING SCENARIO WITH GREATER CONTAGION EFFECTS

The medium contagion scenario described in the previous section implied that a severe shock to Chinese economic growth would have a significant impact on emerging market equities, but a muted impact on developed market and global equities. For risks to Chinese economic growth to seriously threaten long-term global growth and global equity returns, both the Chinese equity market cap and China's level of global economic integration would need to increase substantially. At current growth rates for major developed and emerging market economies, this process would take years.

However the dramatic increase in the VIX during the last week of August and the persistence of lower US and global equity values through September could reflect investors' concern that a hard landing in China could result in more pronounced ripple effects to developed markets. In particular, in times of market turmoil, investors could perceive Chinese trade linkages with the rest of the world to be deeper than they actually are and possibly overreact.

In other words, carefully designed stress tests require an understanding of both the relevant shocks and investors' beliefs about the evolution of economic and market trends. The modeling framework supporting the Macroeconomic Risk Model and RiskManager's predictive stress test can handle both aspects of the stress test design. For example, as shown in Figure 6, if China is perceived to be fully integrated economically with the rest of the world (on par with the US), shocks to Chinese economic growth could carry a much greater impact on US, developed market and global economic growth.

More precisely a 100 bps shock to Chinese growth could now move US growth by about 40 bps (versus 20 bps in the low contagion scenario). In turn, the response of global equities to a China hard landing (a two-standard deviation or 5.2% drop in Chinese growth) could now become more pronounced. Indeed, Figure 6 shows that under this high contagion scenario, global equities could drop by 14% compared to only 4.8% in the medium contagion scenario. The drop in EM equities (-14%), however, is only slightly larger.

Figure 7 also shows that Japanese equities could plunge by 19% (versus 9% under the low contagion scenario). The declines in US, Japanese 10-year government bond yields, and the increase in US BBB credit spread could become twice as large under the high contagion relative to the medium contagion scenario.

Note that in this high contagion scenario, the change to the copper price remains the same, as this has been modeled in relation to the drop in Chinese equities. The VIX Index is shocked by 40%, which is in line with the shock observed on August Black Monday.

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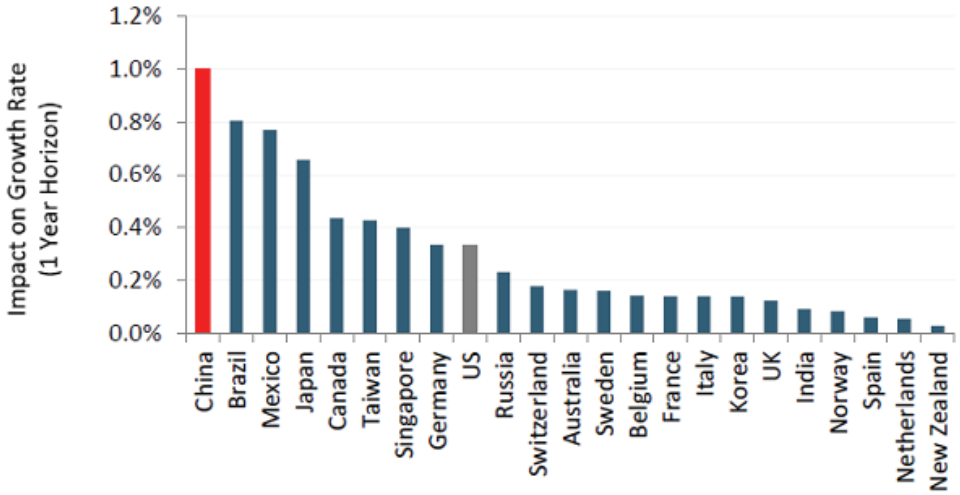
Figure 6: High Contagion Scenario: Impact of 100 bps Shock to Chinese Real GDP Growth



Source: MSCI

Figure 7: Core Risk Factor Shocks in the High Contagion Scenarios

Core Risk Factor	Medium Contagion Scenario Shock
MSCI Japan	-19%
MSCI EM	-14%
MSCI ACWI + FM	-14%
MSCI China A + B + H	-25%
USD Govt 10Y	-35bps
JPY Govt 10Y	-20bps
USD All Sectors BBB 10Y	-11bps
LME Copper 0M	-11%
VIX	+40%

Source: MSCI. Note: For equity risk factors, the shocks refer to the relative changes to the value of the indexes. For interest rate and credit risk factors, the shocks refer to absolute changes in the yields.

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4. IMPACT ON A MULTI-ASSET CLASS PORTFOLIO

Both the medium and high contagion China hard landing stress tests were applied to a global balanced portfolio of equities, bonds and credits (Figure 8). To propagate the shocks of the core market risk factors to the portfolio risk factors, a predictive stress test was set up in RiskManager. A set of best practice guidelines were followed in order to reduce the prediction error in the propagation step. A first important principle is to select a set of core market risk factors that are relevant to a Chinese hard landing scenario and have a high explanatory power for the portfolio risk factors. A second is that the covariance matrix on which the prediction is based should also be compatible with the core market risk factor shocks. Both criteria were assessed with a set of predictive stress test diagnostics. The details are discussed in the Appendix.

Figures 9 and 10 display the results of the medium and high contagion stress tests, respectively, broken down by index and country. For the medium contagion scenario, the global balanced portfolio would lose 3%, mainly driven by the 4.9% drop in the MSCI ACWI Index value. The return impact to the fixed income portfolios would be much more muted; a 90 basis point decline in both emerging market debt (JPM EMBIG and JPM CEMBI) and the high-yield bond index (BofA Merrill Lynch Global Bond Index), whereas the government debt index (JP Morgan Global Bond Index) would gain 70 basis points.

For the high contagion scenario, the same portfolio would drop by 8.4%, driven mostly by the much larger loss on MSCI ACWI of 14%. Also, emerging market and high-yield bond portfolios would decline by larger amounts, with losses ranging between 130 bps and 210 bps. The government debt index would gain 170 bps.

Figure 8: Balanced Portfolio of Equities and Fixed Income

Asset Class		Index	Weight
Equity	Global	MSCI ACWI	60%
Fixed Income	DM Government Bonds	JPM Global Bond Index	20%
	DM High Yield Corporate Bonds	Merrill Global High Yield Index	10%
	EM Government Bonds	JPM EMBIG	5%
	EM Corporate Bonds	JPM CEMBI	5%

Source: MSCI

The potential impact on individual country stocks and bonds is now examined. Under the medium contagion scenario, Hong Kong and United Arab Emirates (one of China's most important economic partners in the Gulf region) equities would drop by more than 10%

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Figure 9: Medium Contagion Scenario – Impact on the Balanced Portfolio, by Country

	JPM Global Bond Index	BofA Merrill Lynch Global Bond index	JPM EMBIG	JPM CEMBI	MSCI ACWI
Total	0.7%	-0.9%	-0.9%	-0.9%	-4.8%
Argentina		-0.2%	0.2%	0.1%	
Australia	0.7%	3.5%	0.6%	0.2%	-3.5%
Austria		0.5%		0.3%	-6.8%
Bangladesh		-2.5%		-2.5%	
Belgium	0.6%	0.2%			-7.2%
Brazil		-1.6%	-3.6%	-3.3%	-6.6%
Canada	0.8%	-1.2%		-1.4%	-3.6%
Chile		-1.5%	-0.1%	-1.3%	-4.2%
China		0.0%	-0.3%	-0.2%	-21.4%
Colombia		-4.0%	-0.5%	-2.6%	-4.2%
France	0.6%	-0.4%			-7.5%
Germany	0.5%	-0.3%			-6.2%
Great Britain	1.6%	-0.5%	-1.8%	-0.6%	-5.8%
Hong Kong		-0.6%	-0.1%	0.0%	-14.4%
India		-0.8%	-0.1%	-0.2%	-4.7%
Indonesia		-2.3%	-1.9%	-2.2%	-5.7%
Italy	0.1%	-0.6%			-5.7%
Japan	0.1%	-0.6%			-9.5%
Netherlands	0.5%	-2.4%	-0.5%	-1.3%	-6.7%
New Zealand		-1.4%			1.1%
Norway		-0.8%		0.3%	-5.6%
Russian Federation			-1.1%		-5.0%
Saudi Arabia		-0.2%			
Singapore		0.0%		0.3%	-6.1%
South Africa		-1.2%	-0.7%	-1.4%	-5.7%
South Korea		-0.4%		-0.2%	-7.3%
Spain	0.3%	-2.5%			-6.6%
Switzerland					-3.0%
Taiwan					-7.9%
Thailand		-0.2%		0.0%	-5.7%
United Arab Emirates		-8.5%		-0.3%	-11.0%
United States	1.0%	-0.6%	-2.9%	-0.1%	-2.6%

Source: MSCI

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Figure 10: High Contagion Scenario: Impact on the Balanced Portfolio, by Country

	JPM Global Bond Index	Merrill Global High Yield Index	JPM EMBIG	JPM CEMBI	MSCI ACWI
Total	1.7%	-2.1%	-2.0%	-1.3%	-14.0%
Argentina		0.0%	0.6%	0.5%	
Australia	1.5%	-1.9%	0.8%	-0.2%	-9.5%
Austria		-1.9%		-0.9%	-19.9%
Bangladesh		-3.4%		-3.4%	
Belgium	1.3%	0.3%			-16.0%
Brazil		-1.8%	-5.2%	-3.5%	-11.2%
Canada	1.8%	-2.1%		-5.0%	-11.7%
Chile		-2.3%	-0.5%	-1.5%	-8.6%
China		-0.1%	-0.7%	-0.3%	-20.3%
Colombia		-4.8%	-5.7%	-3.3%	-11.3%
France	1.2%	-1.4%			-17.6%
Germany	1.0%	-1.4%			-16.5%
Great Britain	3.4%	-1.8%	-3.2%	-1.4%	-13.9%
Hong Kong		-0.9%	-0.3%	0.2%	-15.0%
India		-0.8%	0.1%	0.5%	-9.3%
Indonesia		-2.9%	-4.2%	-2.6%	-9.4%
Italy	0.2%	-2.6%			-17.1%
Japan	1.8%	-1.1%			-19.3%
Netherlands	1.1%	-3.8%	-1.1%	-2.0%	-17.4%
New Zealand		-6.1%			-0.8%
Norway		-1.7%		0.6%	-14.0%
Russian Federation			-5.0%		-10.8%
Saudi Arabia		0.8%			
Singapore		-0.3%		0.4%	-11.5%
South Africa		-3.0%	-3.7%	-1.4%	-10.8%
South Korea		-0.5%		0.0%	-8.3%
Spain	0.6%	-0.7%			-17.3%
Switzerland					-13.3%
Taiwan					-10.5%
Thailand		-0.2%		-0.8%	-8.7%
United Arab Emirates		-12.5%		-0.3%	-18.5%
United States	2.0%	-1.7%	-4.7%	-1.3%	-13.3%

Source: MSCI

For most other countries, a potential decline is seen in equity value between -8% and -3%. Turning to fixed income, sovereign debts for countries in the JPM Global Bond Index would gain value, reflecting a possible flight to quality. Within the Merrill Global High Yield Index, large price drops were observed for United Arab Emirates and Colombia high yield bonds, and general declines in most markets except Australia, Austria, and Belgium.

Under the high contagion scenario, the impact on developed equity markets would be more pronounced, ranging from -20% to -15%, depending on the country. For bonds, larger gains were observed overall to Developed Markets government debt value (from 0.2% to 2%) and larger declines in low rated developed markets credit value (up to 12. 5%).

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CONCLUSION

China's Black Monday renewed concerns from investors about a possible hard landing. As global economic uncertainty persists in the markets, a coherent and structured approach to assess macroeconomic and market scenarios and their impact on investors' portfolios becomes critical. This paper illustrates how investors can use a carefully designed stress test to quantify the potential impact of a China hard landing on global multi-asset class portfolios.

The first step in systematically evaluating a macroeconomic scenario is to define the baseline. The purpose of the baseline scenario is to set bands against which stress scenarios can be measured. The MSCI Macroeconomic Risk Model can be used to define such a baseline scenario, as well as provide confidence bands around the baseline.

Next, modeled investors' beliefs about how economic and market trends might evolve were modelled, including their perception of possible contagion effects. Using trade linkages specific to each pair of countries, a medium contagion scenario was defined, reflecting that China's economy is still not fully integrated with the rest of the world. However, in times of market turmoil, investors could perceive that greater integration exists than actually is the case and overreact. In this high contagion scenario, investors believe the Chinese economy is fully integrated in the global economy (akin to the US).

Finally, the effects of the scenario were traced to asset returns. To this end, the MSCI Macroeconomic Risk Model's assessment of each scenario's impact on a set of core market risk factors was combined with MSCI's predictive stress testing capabilities, to propagate the effect of the scenario to portfolio risk factors.

The findings indicate that the prospect of an economic hard landing in China may significantly impact Chinese, Emerging and Japanese equity markets. However, the impact on globally diversified multi-asset class portfolios would greatly depend on investors' perceived degree of economic contagion from shocks to Chinese growth to the rest of the world. While the loss could be muted (-3.0%) under the medium contagion scenario, it could be more severe (-8.4%) under the high contagion scenario.

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ENDNOTES

1. The MSCI Macroeconomic Risk Model is a structured global model that generates timely forecast scenarios of key macroeconomic factors, such as Gross Domestic Product and inflation. The model traces their effects on global asset class, strategy and selected market risk factor returns over multiple time horizons. In turn, RiskManager's predictive stress testing module can propagate these scenarios to all other market risk factors and institutional global multi-asset class portfolios.

2. The negative 5.2 percentage point shock to Chinese real GDP growth materializes over the course of a year. However, this shock to the expected future GDP growth rate is priced in almost immediately by investors in the model.

3. The index captures large- and mid-cap representation across China H shares, B shares, Red chips and P chips.\

4. We chose not to shock FX rates, as these are heavily influenced by central bank intervention in China and Asia and hence difficult to forecast in a systematic fashion.

5. Note that this is the general formula for the Mahalanobis distance. In our analysis, we assume no drift, i.e. $\mu=0$.

6. Note that the results are identical for the low and high contagion scenarios, as the shock size does not play a role, only the selected core factors.

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APPENDIX: DESIGNING THE CHINA HARD LANDING STRESS TEST

This section describes the propagation of the core market risk factor shocks onto all other risk factors impacting a portfolio. To do this, RiskManager's predictive stress test tool was used, which necessitated a number of parameter choices. The following sections outline the risk settings chosen and how well they performed in terms of predictive stress test diagnostics. It should be noted that the focus in this paper is on assessing the impact of a China hard landing on global diversified multi-asset portfolios. For a portfolio concentrated in a single country or region, other country-specific market risk factors should be considered.

A1. Risk settings: Estimation window and return horizon

For the predictive stress test, the estimation window and the return horizon needed to be defined, which determined the choice of returns on which the regression was run. For the return horizon, a bi-weekly frequency was adopted, as this brought the magnitude of the returns more closely into line with the core factor shocks.

The choice of estimation window was more complex. The main aim was to capture the covariance matrix and dynamics of a China slowdown scenario. In recent years, there has been no period in which China clearly dominated market events. A slowdown occurred in the Chinese economy during the 2008 financial crisis, but this was not caused by the Chinese economy itself. Therefore, a recent timeframe is the most appropriate estimation window for use in this context. Moreover, the market correction at the end of August has provided a more stressed covariance matrix. In summary, a one-year trailing lookback window with overlapping bi-weekly returns and a decay factor equal to one was adopted.

A2. Stress test diagnostics: Mahalanobis Distande (MD)

A first step in diagnosing a predictive stress test is to observe whether the covariance matrix in the given estimation window is compatible with the core factor shocks that have been specified. A measure for quantifying this is the Mahalanobis Distance (MD):[5]

$$\mathrm{MD}(x) = \sqrt{(x-\mu)' \Sigma^{-1} (x-\mu)}.$$

MD is a multivariate extension of the z-score. Analogous to the z-score, MD measures the number of standard deviations between a certain observation and the mean, taking the multivariate covariance matrix into account. Under the assumption of normally distributed risk factor returns, MD^2 asymptotically follows a x^2 distribution, which allows us to calculate p-values. The p-value thus indicates how much of an outlier the given shock is in the specified estimation window. The larger the MD, the larger the prediction noise in the predictive stress test. Hence, it is crucial to strive for a moderate level of MD. Note that in the calculation of MD, only the core factors play a role, not the predicted factors. In other

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words, this analysis can be performed without knowledge of the portfolio the stress test will be applied to. Calculating MD for the medium contagion China hard landing stress test scenario with the risk settings as defined in the previous section, we obtained an MD equal to 6.0 and a corresponding p-value equal to 4e-05. This can be reduced by applying a *structural* approach, which limited the propagation of core factor shocks to risk factors of the same type. The structural approach is summarized in Figure 11. For example, a commodity risk factor would only be impacted by the core factor shock on the copper price. It should also be noted that in this setup, credit spreads were predicted based on equity shocks. Furthermore, we made a distinction between Developed Market (DM) debt and Emerging Market (EM) debt, as will be discussed later.

Figure 11: Medium Contagion Scenario Stress Test Diagnostics

Risk type	Core Risk Factors	Shock	MD	p-value
Full Stress Test (DM)	All below core factors except Interest Rates (EM)		6.0	4e-05
Equity	MSCI Japan MSCI EM MSCI ACWI MSCI China A + B + H	-9% -12% -4.8% -25%	5.2	2e-05
Interest Rates (DM)	USD Govt 10Y JPY Govt 10Y USD All Sectors BBB 10y	-17bps -10bps -5bps	2.1	0.2
Interest Rates (EM)	USD Govt 10Y JPY Govt 10Y MSCI EM	-17bps -10bps -12%	4.3	3e-04
Commodity	LME Copper 0M	-11%	3.0	3e-03
Volatility	VIX	+25%	1.0	3.0
CDS Spread Curve	MSCI Japan MSCI EM MSCI ACWI MSCI China A + B + H	-9% -12% -4.8% -25%	5.3	1e-05

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Figure 11 reveals that the structural approach enables us to reduce the MD significantly compared to a stress test in which we do not limit propagation within risk types. The table also displays the p-values, which allow for the measurement of the plausibility of the shock in the estimation window. For interest rates and volatilities, the shock was not very extreme. For commodities, equities (and also credit spreads) and the combined interest rate and equity shocks, the p-values were much smaller. This may potentially lead to large prediction errors, especially when the R-squared is low.

Turning attention to the high contagion scenario of which the MD stats are displayed in Figure 12, observe that MD gets larger for the full stress test, as well as for the structured approach (with the exception of Copper and VIX). Generally, when the shock size increases, we will see an increase in MD. Note, however, that for the equity stress test, MD is not much larger, even though the shocks on MSCI Japan and MSCI ACWI have increased significantly. This can be explained by the fact that the direction of the shock is more plausible, i.e., the shocks on these risk factors and MSCI China and MSCI EM jointly are more in line with the covariance matrix.

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Figure 12: High Contagion Scenario Stress Test Diagnostics

Risk type	Core Risk Factors	Shock	MD	p-value
Full Stress Test (DM)	All below core factors except Interest Rates (EM)		13	0
Equity	MSCI Japan MSCI EM MSCI ACWI MSCI China A + B + H	-19.4% -14.3% -14.0% -25.0%	6	4e-07
Interest Rates (DM)	USD Govt 10Y JPY Govt 10Y USD All Sectors BBB 10y	-35bps -20bps -11bps	4.1	6e-04
Interest Rates (EM)	USD Govt 10Y JPY Govt 10Y MSCI EM	-35bps -20bps -14.3%	5.9	1e-07
Commodity	LME Copper 0M	-11%	3	3e-03
Volatility	VIX	+40%	1.3	0.2
CDS Spread Curve	See Equity stress test		6	4e-07

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A3. Stress test diagnostics: R-Squared

The next determinant of prediction noise used was R-squared, which measures the strength of the historical relationship between the core factors and the predicted factors. As such, the calculation of R-squared requires knowledge of the portfolio to which the stress test is applied. We assessed R-squared for the structural and non-structural approaches on a number of benchmark portfolios or risk factors, the results for which are shown in Figure 13.[6]

The non-structural approach always produces the highest R-squared, as this regression includes more core factors compared to the individual risk type based stress tests. However, since the MD is much larger for the non-structural approach, we trade off lower R-squared with lower MD, as the latter generally has a stronger impact on prediction noise. Turning to the structured approach, observe that the core factors selected in each risk type category generally have sufficiently high R-squared (the relevant blocks are highlighted with a black border in Figure 13). Note that the interest rate stress test does not perform particularly well for EM debt, with R-squared values around 0.15. Therefore, a modified interest rate stress test has been created for EM debt, in which the risky US BBB interest rate is replaced with an equity factor, MSCI EM. EM credit spreads are more correlated with EM equities than with DM credit spreads.

A4. Predicted benchmark returns

Finally, Figures 14 and 15 show the predicted return, the prediction error and the t-stat for each benchmark index for both stress tests. All the predictions are significant, with an absolute value of the t-stat larger than two. The main results of the stress test can be summarized as follows: equities fall in value, developed market debt rises, emerging market debt falls and commodities also fall, while volatility spikes and credit spreads widen. These are all flight-to-quality effects in times of market turbulence.

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Figure 13: Aggregate R-squared for a Selection of Benchmark Indexes

Benchmark Index	Equity	IR	IR + EQ (EM)	Comm.	Vol.	Full (DM)
MSCI Brazil	0.61	0.06	0.54	0.07	0.09	0.68
MSCI Europe	0.84	0.14	0.54	0.06	0.60	0.87
MSCI Mexico	0.73	0.15	0.62	0.10	0.43	0.74
MSCI Taiwan	0.64	0.15	0.62	0.12	0.27	0.68
MSCI USA	0.95	0.29	0.49	0.03	0.82	0.96
US 10Y Treasury Bond	0.17	1.00	1.00	0.21	0.10	1.00
10Y Treasury ZC Bond USD	0.16	1.00	1.00	0.21	0.10	1.00
10Y Treasury ZC Bond GBP	0.08	0.27	0.29	0.01	0.00	0.47
10Y Treasury ZC Bond EUR	0.15	0.10	0.08	0.03	0.04	0.37
10Y US All Sector BBB zero coupon	0.08	1.00	0.69	0.03	0.00	1.00
JPM EMBIG	0.62	0.16	0.53	0.06	0.27	0.66
JPM CEMBI	0.59	0.13	0.56	0.03	0.30	0.62
Aluminium	0.27	0.02	0.11	0.14	0.01	0.45
Copper	0.12	0.33	0.26	1.00	0.02	1.00
Gold	0.27	0.34	0.27	0.03	0.10	0.55
Oil	0.31	0.32	0.49	0.23	0.06	0.62
V Stoxx	0.52	0.10	0.26	0.00	0.60	0.64
VIX	0.82	0.24	0.49	0.02	1.00	1.00
Itraxx Europe	0.40	0.13	0.23	0.00	0.33	0.42
CDX NA	0.71	0.37	0.58	0.08	0.57	0.77
CDX EM	0.57	0.17	0.47	0.14	0.27	0.60

Source: MSCI

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Figure 14: Medium Contagion Scenario: Predicted Returns, Prediction Errors and T-Stats for Benchmark Indexes

		deltaPV	deltaPV SE	t-stat
Equity	MSCI Brazil	-14.9%	1.5%	-10
	MSCI Europe	-4.4%	0.4%	-10
	MSCI Mexico	-5.6%	0.7%	-9
	MSCI Taiwan	-10.0%	0.7%	-14
	MSCI USA	-2.8%	0.2%	-14
Interest Rates	US 10Y Treasury Bond	1.5%	0.0%	>100
	10Y Treasury ZC Bond USD	1.7%	0.0%	
	10Y Treasury ZC Bond GBP	1.3%	0.2%	7
	10Y Treasury ZC Bond EUR	0.4%	0.2%	2
	10Y US All Sector BBB zero coupon	0.5%	0.0%	
IR + EQ (EM)	JPM EMBIG	-3.5%	0.2%	-14
	JPM CEMBI	-3.0%	0.2%	-16
Commodity	Aluminium	-3.8%	0.6%	-6
	Copper	-10.9%	0.0%	
	Gold	1.5%	0.6%	3
	Oil	-11.5%	1.4%	-8
Volatility	VIX	25.0%	0.0%	
Credit Spreads	Itraxx Europe	85.6%	29.8%	3
	CDX NA	150.0%	18.5%	8
	CDX EM	13.3%	2.6%	5

Source: MSCI. For a small number of instruments standard errors are not displayed as these are core factors. Moreover, for CDX instruments, the return relative to the absolute value of the present value is calculated. For all CDX instruments, the shock amount is the percentage change in the value of a hypothetical CDX contract which buys protection and pays 100 bps.

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Figure 15: High Contagion Scenario: Predicted Returns, Prediction Errors and T-Stats for Benchmark Indexes

		deltaPV	deltaPV SE	t-stat
Equity	MSCI Brazil	-16.1%	1.7%	-10
	MSCI Europe	-15.2%	0.5%	-32
	MSCI Mexico	-13.2%	0.8%	-18
	MSCI Taiwan	12.2%	0.8%	-15
	MSCI USA	-13.5%	0.2%	-59
Interest Rates	US 10Y Treasury Bond	3.1%	0.0%	>100
	10Y Treasury ZC Bond USD	3.5%	0.0%	
	10Y Treasury ZC Bond GBP	2.6%	0.4%	7
	10Y Treasury ZC Bond EUR	0.8%	0.5%	2
	10Y US All Sector BBB zero coupon	1.1%	0.0%	
IR + EQ (EM)	JPM EMBIG	-4.1%	0.3%	-12
	JPM CEMBI	-3.8%	0.3%	-15
Commodity	Aluminium	-3.8%	0.6%	-6
	Copper	-10.9%	0.0%	
	Gold	1.5%	0.6%	3
	Oil	-11.5%	1.4%	-8
Volatility	VIX	40.0%	0.0%	
Credit Spreads	Itraxx Europe	486.8%	34.0%	14
	CDX NA	540.4%	21.1%	26
	CDX EM	39.0%	3.0%	13

Source: MSCI. For a small number of instruments standard errors are not displayed as these are core factors. Moreover, for CDX instruments, the return relative to the absolute value of the present value is calculated. For all CDX instruments, the shock amount is the percentage change in the value of a hypothetical CDX contract which buys protection and pays 100 bps.

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