

Global Memory Tech

BofA memory indicator: downturn over; surpassed mid-cycle in Nov 2023

Industry Overview

Above mid-cycle for the first time since 1H22

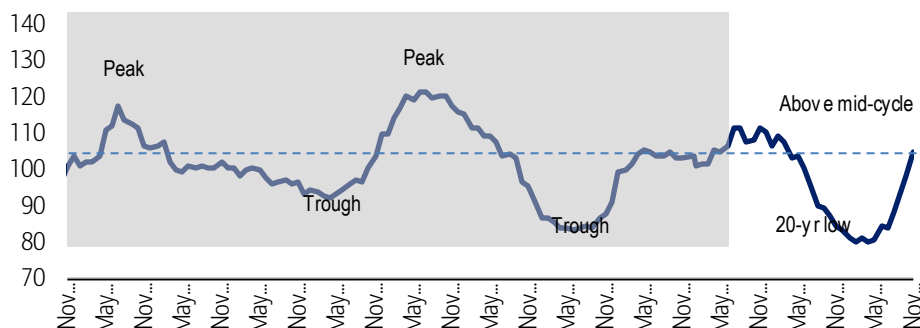
Our memory indicator exceeded mid-cycle (100) in Nov-23 for the first time since 1H22 (100-109). In fact, the indicator hit 20-year low through Dec-22 – May-23 (80-83) along with severe price erosion and exceptionally low bit growth, and then gradual recovery in Jul/Aug/Sep/Oct (84/88/94/99). Nov turnaround is mostly based on NAND spot-price (up 50%+ YoY), DRAM/NAND billings (up 25%+ YoY) and Korea semis exports (+13%). DRAM ASP (mostly contract price) also posted limited YoY decline (only -7% vs -50%+ in 1H23), but NAND ASP still showed -23% (+6% MoM) despite spot rally (OEM's resistance seen).

Dec-Jan prices/sales/exports collectively in upward trends

Dec industry data recovered further led by NAND spot-price (+64% YoY), Nanya Tech's sales (+32%) and Korea's semis exports (+22%). In Jan, NAND spot price rally could be limited given already doubled vs Jul-low, but time to see commodity DRAM (DDR4) price recovery coupled with chipmakers' significant production cut (through 2023). HBM (100%+ order growth still seen) will continuously lead to blended ASP increase, in our view. Our memory indicator will be updated with WSTS' Dec billings/ASP in early Feb.

Exhibit 2: BofA Memory Indicator is derived from YoY change in price/exports/billings

In Nov, the indicator (105) hit year-high level and even surpassed the mid-cycle level (100), driven by strongly recovered NAND spot price, DRAM/NAND billings, and solid Korea semis exports



Source: DRAMeXchange, WSTS, MoTIE Korea, BofA Global Research

The shaded area represents backtested results from January 1991 to March 2021. The unshaded area represents actual performance since April 2021. This performance is backtested up to March-2021, and does not represent the actual performance of any account or fund. Back-tested performance depicts the theoretical (not actual) performance of a particular strategy over the time period indicated. No representation is being made that any actual portfolio is likely to have achieved returns similar to those shown herein.

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Exhibit 1: BofA Memory Indicator

Nov indicator (105) finally above mid-cycle level (100)

YoY trend	Sep-23	Oct-23	Nov-23	Dec-23
DRAM spot	Down	Down	Down	Down
NAND spot	Down	Down	Up	Up
Korea exports	Down	Down	Up	Up
DRAM ASP	Down	Down	Down	na
NAND ASP	Down	Down	Down	na
DRAM billings	Up	Up	Up	na
NAND billings	Down	Up	Up	na
BofA Indicator	94	99	105	na

Source: DRAMeXchange, WSTS, MoTIE Korea, BofA Global Research

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DRAM: Dynamic random-access memory**NAND:** Not-AND memory**ASP:** Average selling price**HBM:** High bandwidth memory**OEM:** Original equipment manufacturer

See Methodology section to understand how we constructed our indicator (standardized YoY changes of seven components).

More abbreviations are in the Appendix section on page 9.

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Refer to important disclosures on page 10 to 11.

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Timestamp: 08 January 2024 10:15AM EST

Full details of BofA Memory Indicator

Exhibit 3: Seven components of BofA Memory Indicator – MoM and YoY trends (back-tested)

Further YoY recovery seen in DRAM/NAND billings for November and NAND spot/Korea exports for December; MoM recovery also well-expected in December across all seven components

	Dec-22	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Aug-23	Sep-23	Oct-23	Nov-23	Dec-23
MoM													
DRAM spot price	Down	Down	Down	Down	Down	Up	Down	Down	Down	Up	Up	Up	Up
NAND spot price	Down	Down	Down	Down	Down	Down	Down	Down	Up	Up	Up	Up	Up
Korea semis exports	Up	Down	Down	Up	Down	Up	Up	Down	Up	Up	Down	Up	Up
DRAM ASP	Down	Down	Up	Down	Up	Up	Down	Up	Up	Up	Up	Down	na
NAND ASP	Down	Up	Down	Down	Up	Down	Down	Up	Down	Down	Up	Up	na
DRAM billings	Up	Down	Up	Up	Down	Up	Up	Down	Up	Up	Down	Up	na
NAND billings	Down	Down	Up	Up	Down	Up	Up	Down	Up	Up	Down	Up	na
Avg of MoM trend	Down	Down	Up	Up	Down	Up	Up	Down	Up	Up	Down	Up	na
YoY													
DRAM spot price	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down
NAND spot price	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Up	Up
Korea semis exports	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Up	Up
DRAM ASP	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	na
NAND ASP	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	na
DRAM billings	Down	Down	Down	Down	Down	Down	Down	Down	Down	Up	Up	Up	na
NAND billings	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Up	Up	na
Avg of YoY trend	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Down	Up	na
Memory indicator	83	81	80	81	80	81	85	84	88	94	99	105	na

Source: DRAMeXchange, WSTS, MoTIE Korea, BofA Global Research estimates.

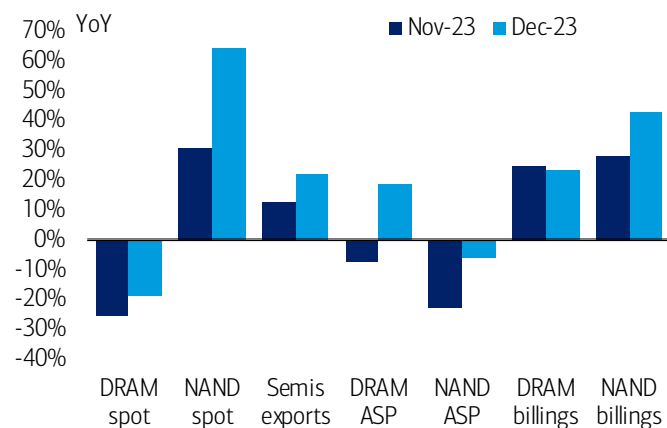
Notes: *November results recovered in all aspects in terms of MoM growth except DRAM ASP

**For December, only spot prices and exports are reported so far

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Exhibit 4: Seven components of BofA Memory Indicator – YoY

Dec industry data are expected to be better vs Nov – YoY increase in NAND billings (price x volume) and NAND spot outstanding



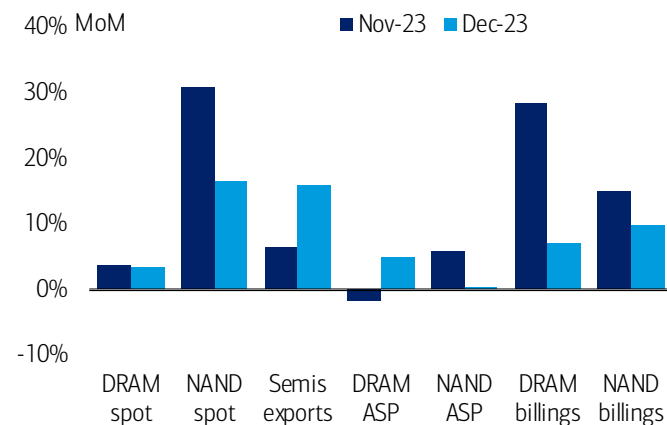
*All November data and December spot/exports are actual, but December billings are our estimates

Source: DRAMeXchange, WSTS, MoTIE Korea, BofA Global Research estimates

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Exhibit 5: Seven components of BofA Memory Indicator – MoM

Most of the components recovered well MoM in Nov/Dec 2023



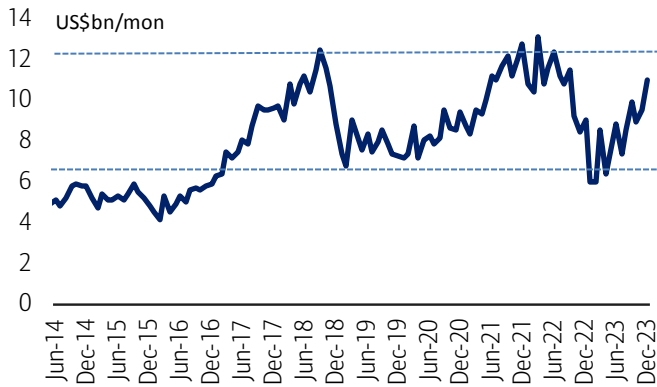
* All November data and December spot/exports are actual, but December billings are our estimates

Source: DRAMeXchange, WSTS, MoTIE Korea, BofA Global Research estimates

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Exhibit 6: Korea semis exports – US\$bn monthly

Significant improvement seen in December (US\$11.0bn; +16% MoM), but mostly driven by higher bit growth (Samsung) – 20% ASP hike not yet

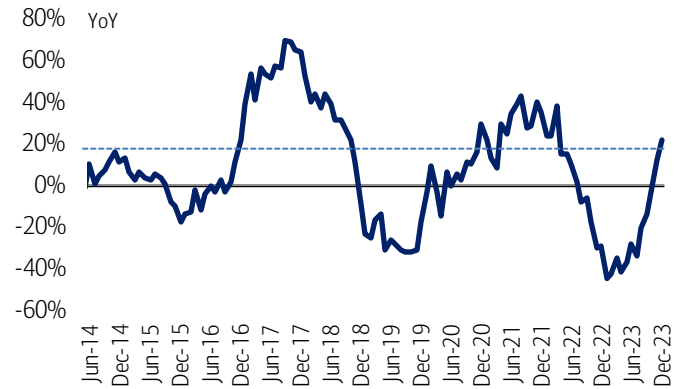


Source: MotIE, BofA Global Research

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Exhibit 7: Korea semis exports – YoY change in monthly US\$bn

Another robust YoY recovery in December (+22%) following a turnaround in November (+13%); of course, ASP recovery also seen but sub-20%

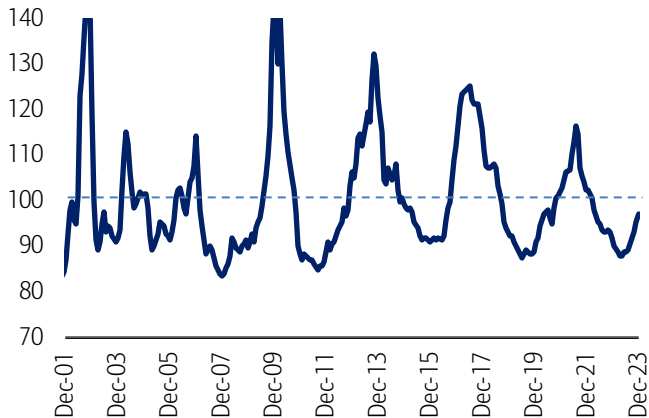


Source: MotIE, BofA Global Research

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Exhibit 8: DRAM spot price - indexed YoY change (historical avg 100)

Still slightly below mid-cycle vs previous peak of 2021

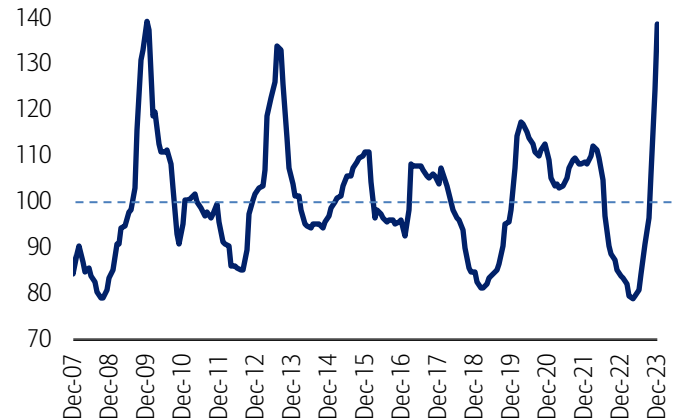


Source: DRAmEXchange, BofA Global Research

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Exhibit 9: NAND spot price – indexed YoY chg (historical avg 100)

Already hit peak level but downside low given 2023 production cut

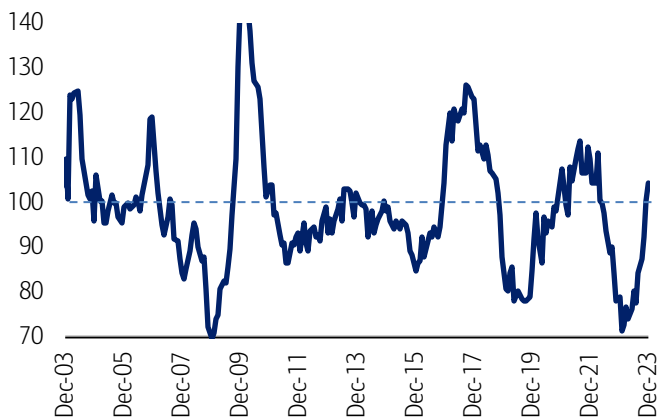


Source: DRAmEXchange, BofA Global Research

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Exhibit 10: Korea semis exports - indexed YoY chg (historical avg 100)

Surpassed mid-cycle level (100) in Dec-23

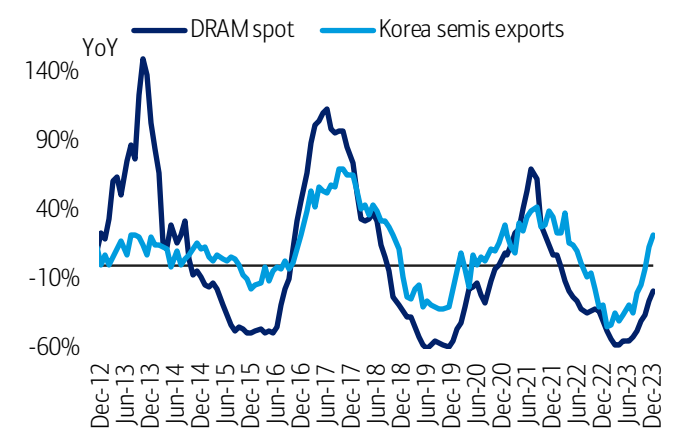


Source: MotIE, BofA Global Research

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Exhibit 11: DRAM spot price and Korea semis exports – YoY change

Korea semis exports growth better than spot due to HBM and DDR5

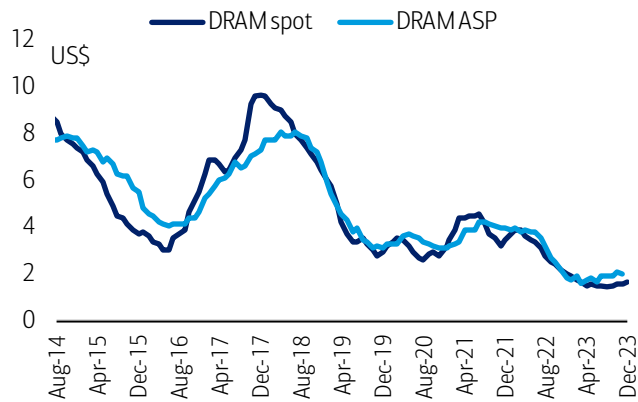


Source: DRAmEXchange, MotIE, BofA Global Research

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Exhibit 12: DRAM spot and ASP trend – month average; 8Gb equiv.

Nov/Dec month-average price still at 10-year low level despite recent rebound

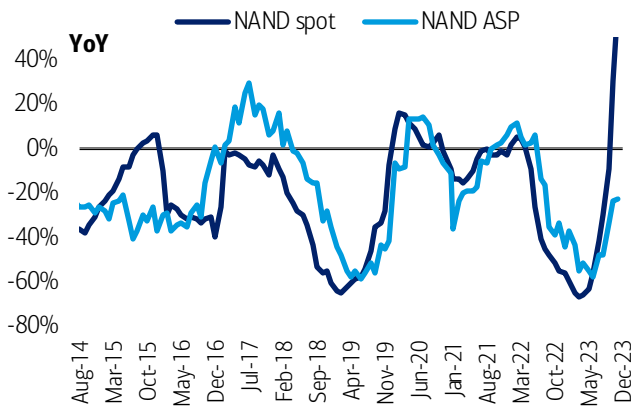


Source: DRAmExchange, WSTS, BofA Global Research

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Exhibit 14: NAND spot and ASP trend – YoY

Dec spot price sharply up (+64% YoY) vs Nov ASP (-23%)

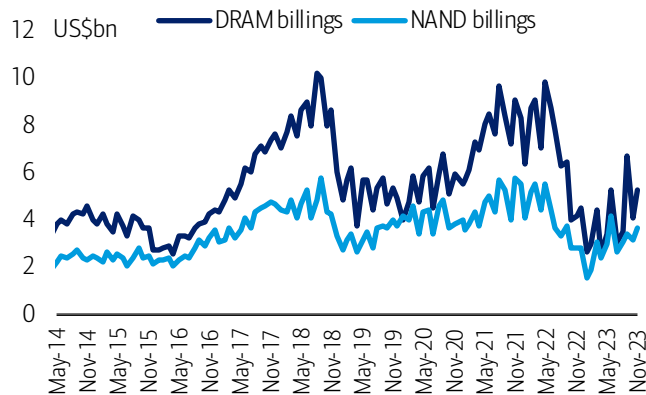


Source: DRAmExchange, WSTS, BofA Global Research

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Exhibit 16: DRAM and NAND billings

Both DRAM and NAND billings recovered well in Nov vs Oct

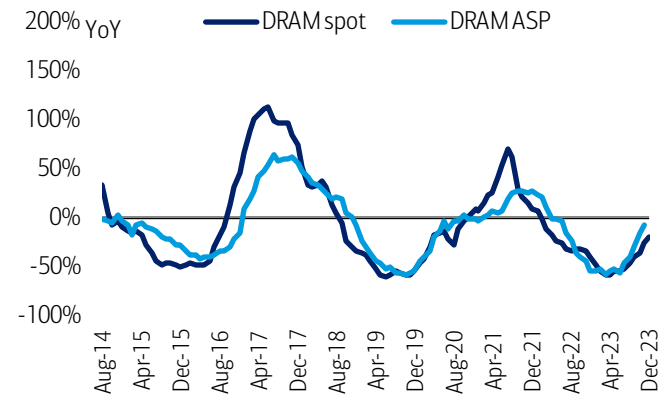


Source: WSTS, BofA Global Research

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Exhibit 13: DRAM spot and ASP change – YoY trend

Still YoY decline seen in both Nov ASP (-7%) and Dec spot (-19%)

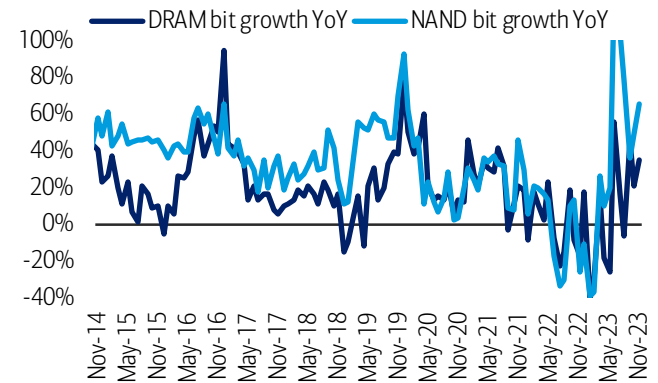


Source: DRAmExchange, WSTS, BofA Global Research

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Exhibit 15: DRAM and NAND bit growth – YoY

Strong rebound - DRAM bit growth at 35% YoY, while NAND increased 66% in Nov (Samsung's aggressive shipment seen)

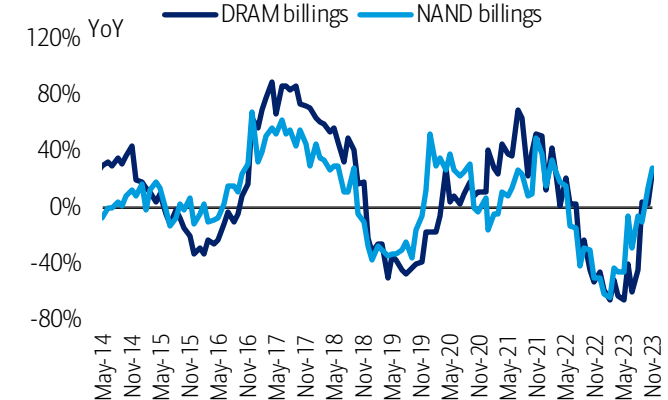


Jun/Jul actual DRAM ASP decline less than what WSTS reported based on major suppliers' 2Q results and guidance. Source: WSTS, BofA Global Research

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Exhibit 17: DRAM and NAND billings change – YoY

Strong YoY recovery in DRAM/NAND billings seen in Nov (up 25%+)

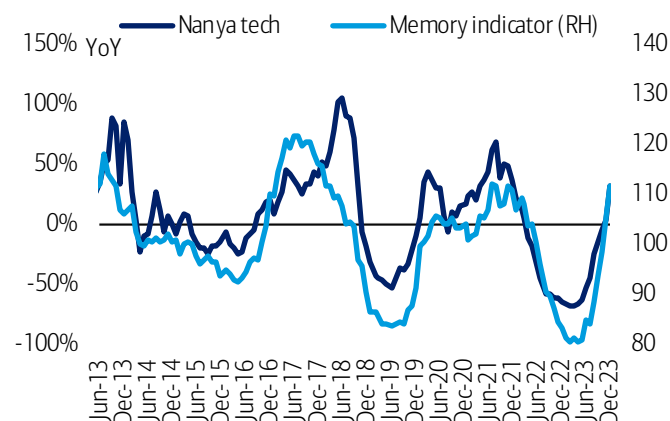


Source: WSTS, BofA Global Research

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Exhibit 18: Nanya Tech monthly and YoY sales vs Memory Indicator

Nanya Tech posted solid recovery in Dec monthly sales (+32% YoY)

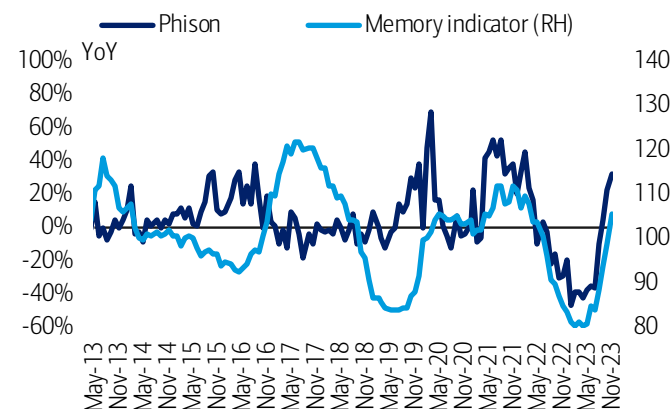


Source: Company report, BofA Global Research

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Exhibit 19: Phison monthly and YoY sales vs Memory Indicator

Strong rebound in Oct/Nov YoY sales (+23%/+32% YoY)

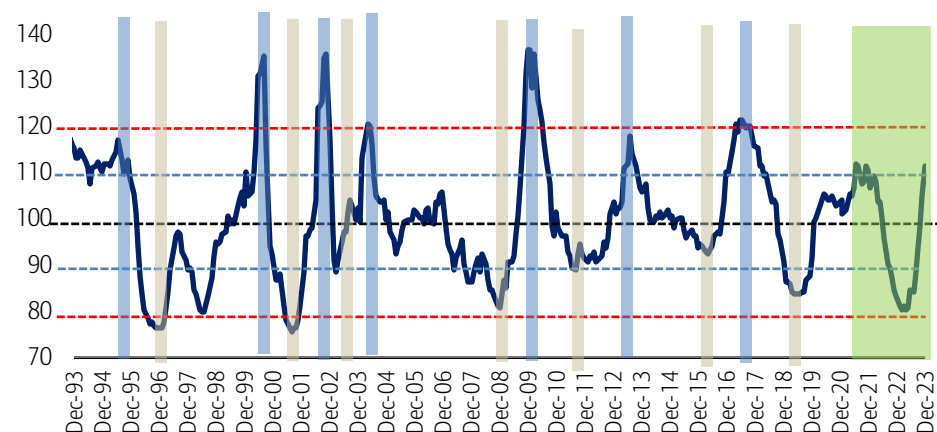


Source: Company report, BofA Global Research

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Exhibit 20: BofA Memory Indicator's overall back-tested trend in the past 30 years

Seven peaks and seven troughs in the past 30 years up to 2020; back to above mid-cycle in Nov-23 following trough cycle in 1H23



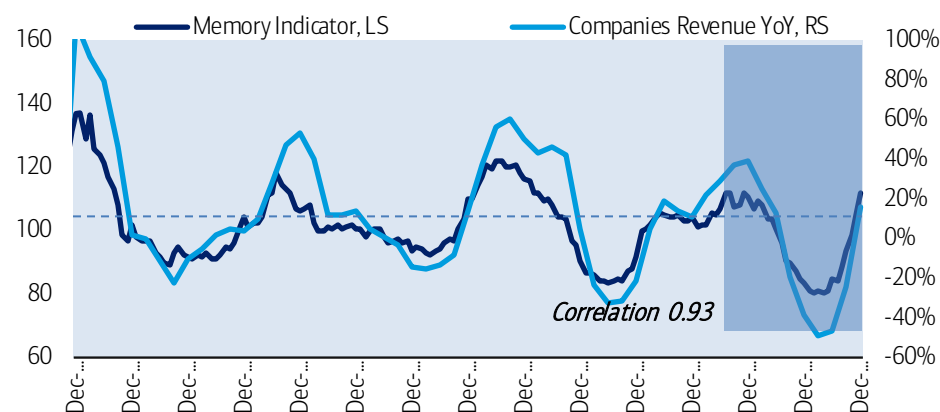
Source: DRAMeXchange, WSTS, MoTIE Korea, BofA Global Research.

*Note: Blue represents Peak, Grey represents Trough, Green represents actual data since April 2021; prior period is back-tested results. This performance is backtested up to March-21 and does not represent the actual performance of any account or fund. Back-tested performance depicts the theoretical (not actual) performance of a particular strategy over the time period indicated. No representation is being made that any actual portfolio is likely to have achieved returns similar to those shown herein.

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Exhibit 21: BofA Memory Indicator is highly correlated with memory companies' revenue growth

Chipmakers which have high exposure to HBM and DDR5 should post earlier earnings turnaround



The companies' revenue YoY is the average of Samsung, Hynix, Micron, and Nanya's year-on-year revenue change

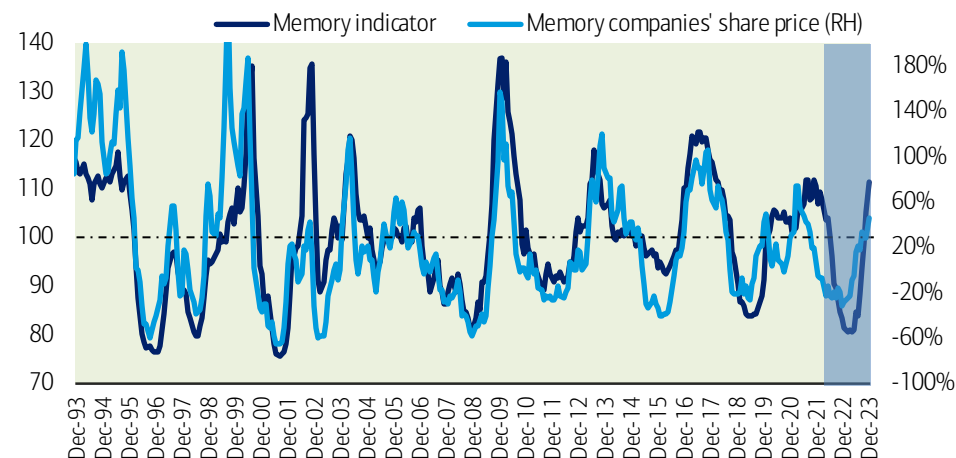
Source: Company report, DRAmExchange, WSTS, MoTIE Korea, BofA Global Research

The light blue shaded area represents backtested results from January 1991 to March 2021. The dark blue shaded area represents actual data since April 2021. This performance is backtested up to March 2021 and does not represent the actual performance of any account or fund. Backtested performance depicts the theoretical (not actual) performance of a particular strategy over the time period indicated. No representation is being made that any actual portfolio is likely to have achieved returns similar to those shown herein. Historic correlation does not necessarily indicate that correlation will continue in the future.

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Exhibit 22: BofA Memory Indicator is highly correlated with stock performance

Memory stock rally slightly muted as of early Jan but memory indicator recovery on track



Note: Memory companies' share price is average of Samsung, Hynix, Micron, and Nanya share price YoY changes

Source: Bloomberg, BofA Global Research

The light green shaded area represents backtested results from January 1991 to March 2021. The blue shaded area represents actual data since April 2021. This performance is backtested up to March 2021 and does not represent the actual performance of any account or fund. Backtested performance depicts the theoretical (not actual) performance of a particular strategy over the time period indicated. No representation is being made that any actual portfolio is likely to have achieved returns similar to those shown herein. Historic correlation does not necessarily indicate that correlation will continue in the future.

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Methodology

We selected our seven components based on what we believe are the key datapoints in understanding the memory cycle. WSTS and DRAMeXchange data represent industry-level numbers, while Korea semiconductor exports represent macro-level data. Our indicator is equal-weighted among the components as memory companies' revenues are not skewed to a singular factor, but rather influenced by supply and demand for both DRAM and NAND. Further, our current methodology shows the most consistent as well as the highest correlation to companies' revenues (0.93 since 2009 on a back-tested basis). Our Indicator was launched on 19 April 2021.

Spot prices are available with the least time lag (given daily trade), while WSTS data are available with around 33-days lag. Our updated indicator is published early every month and provides a preliminary insight into the previous month as well as a final reading of two months prior. For example, our early-Oct 2022 report showed September preliminary and August final values and will provide insights of the 3Q22 results, which will be confirmed by the companies in their late-October results calls. We believe that this would be useful to tech investors, given that memory companies do not announce monthly results (unlike other Taiwanese companies), and also as memory stocks are sensitive to short-term earnings momentum.

Exhibit 23: Seven elements of our memory indicator; all % YoY and equally weighted

DRAM data focused on 1990s and early 2000s, but full coverage with NAND and Korea exports from 2002

Input	Source	Available since	Frequency	Availability
DRAM spot	DRAMeXchange	Feb-00	Daily	End of every day
NAND spot	DRAMeXchange	Nov-06	Daily	End of every day
DRAM WSTS ASP	World Semiconductor Trade Statistics	Jan-91	Monthly	33-day following end-month
DRAM WSTS billings	World Semiconductor Trade Statistics	Jan-90	Monthly	33-day following end-month
NAND WSTS ASP	World Semiconductor Trade Statistics	Jan-04	Monthly	33-day following end-month
NAND WSTS billings	World Semiconductor Trade Statistics	Jan-04	Monthly	33-day following end-month
Korea exports	Ministry of Trade, Industry, and Energy	Jan-02	Monthly	First of the following month

Source: BofA Global Research

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DRAM/NAND spot prices: Spot prices mostly represent the pricing trend of commodity or low-quality chips traded in the spot market. Current mainstream specs are 8Gb DDR4 DRAM and 256Gb 3D NAND.

DRAM/NAND WSTS billings: WSTS billings represent total global DRAM/NAND sales amount (USD basis; units x prices) during a month.

DRAM/NAND WSTS ASP: We derive it from sales (USD-denominated, even for China, Japan and Europe OEM customers) vs. volume (normally converted into 8Gb DRAM and 256Gb NAND equivalents). The WSTS ASP numbers involve more contract prices (normally settled a month or a quarter ago, thus lagging vs. daily spot prices) for the PC/server/mobile memory chips traded between chipmakers and end-users (OEMs, component makers, DRAM/SSD module makers, etc.).

Korea semiconductor exports: Mostly comprises memory chips fabricated by Samsung and SK Hynix. Combined global market share of Samsung and SK Hynix should be 70-80% / 50-60% for DRAM / NAND, respectively, over the past four years (2017-20).

Limitations to our back-testing: We note that not all seven inputs are available from 1990 (when DRAM WSTS ASP YoY value was available). We thus added them as and when the data became available. The other limitation is the exclusion of Kioxia and Western Digital from our target variable analysis due to complexities regarding the two companies' co-owned JV fabs and only NAND-related results (none for DRAM).

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Appendix

DRAM: Dynamic random-access memory

DRAM stores data temporarily using billions of tiny capacitors and transistors to support logic processor on a real-time basis. The processor sends/receives data to/from DRAM. Thus, DRAM's capacity (1Gb, 4Gb, 8Gb), speed (2Ghz, 6Ghz) and low-power consumption (1.1V, 1.05V) are critical for processors (Intel CPU, Qualcomm AP, NVIDIA GPU, etc.).

NAND: Not-AND flash memory

NAND stores data permanently in transistors (vs. DRAM temporarily using both capacitor and transistor). NOR (Not OR) used to be a main flash memory in 1990s and early 2000s, but it has been gradually replaced by NAND at a much lower price in the past 10 years. Most NAND is now fabricated at 3D multi-layer (e.g., Samsung's 128-layer) instead of 2D planar.

Memory price

Memory average selling price (ASP) is simply derived from sales (USD-denominated, even for China, Japan and Europe exports) vs. volume (normally converted into 8Gb DRAM and 256Gb NAND). For e.g., US\$3bn revenue vs. 1bn units (either 8Gb or 256Gb equivalent) implies US\$3 ASP.

Spot-market price (currently around US\$1.5 for 8Gb DRAM vs. 256Gb 3D NAND is at \$2.1) is available on a daily basis vs. contract price (normally settled a month or a quarter ago). Spot-market price usually represents just commodity (PC, mobile) or low-quality chips. Lots of chips offer more value-addition (vs. spot) given customization (e.g., Samsung's server DRAM for AWS) or advanced spec (graphic, low-power, high-speed for DDR5, etc.).

WSTS: World Semiconductor Trade Statistics, affiliated with the SIA (Semiconductor Industry Association) and publishes monthly industry data for global semiconductors including DRAM/NAND.

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