

Cloud Block Storage Benchmark Report

AMAZON WEB SERVICES (AWS), DIGITALOCEAN,
GOOGLE CLOUD PLATFORM (GCP), LINODE, MICROSOFT AZURE, VULTR

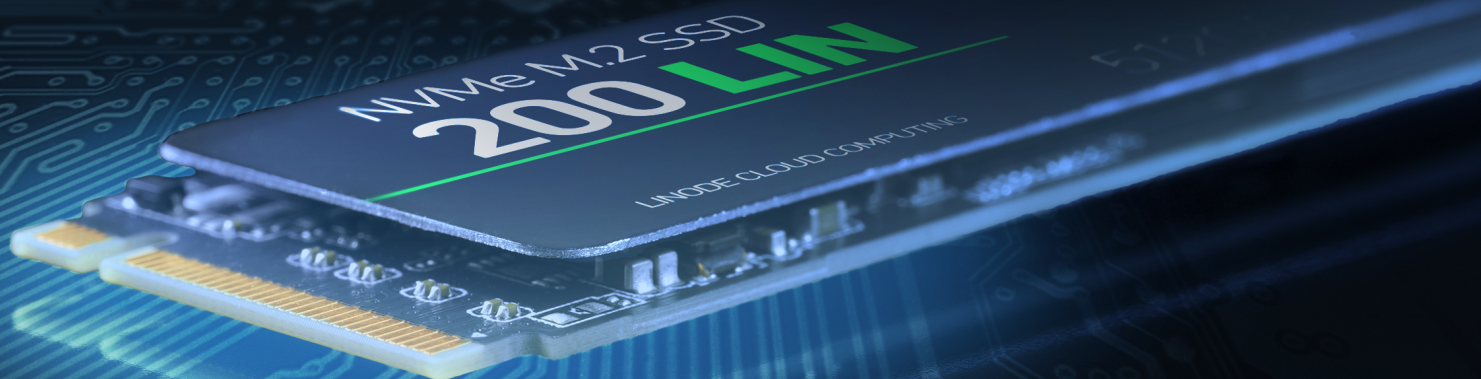


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Introduction

High-performance and reliable cloud-based storage is no longer secondary to the performance power needed to support virtual machines. Block storage is a crucial tool to expand storage capacity beyond what is provided by a virtual machine (VM) and ensures high availability for the data that keeps applications and businesses running. Block storage operates in volumes, where each volume is the equivalent of a separate hard drive that can be attached or removed from a VM. This process allows databases, assets, and other stored files to remain independent from a server, so the data is safe from the risk of server downtime, and you can attach your data to backups or another server. In addition, keeping data separate from your application's other essential underlying infrastructure can help improve performance.

As developers and organizations leverage more data in applications, reliable, attachable, and highly-performant storage is essential to providing a positive customer experience while also adhering to an application's necessary service level agreement (SLA).

If high-performance and reliable block storage is critical for your application, not all cloud providers will meet your needs. In this benchmark report, Cloud Spectator evaluates both CPU performance with block storage volumes attached and database performance to determine the fastest overall performance and value per dollar among large, well-known cloud providers and popular alternative cloud providers.

Key Findings

Cloud Spectator performed benchmarks on both well-known, large cloud providers that dominate the cloud market and alternative cloud providers that offer parity in terms of core cloud products and global availability with competitive pricing. This report is a comprehensive block storage performance assessment with a general CPU performance overview included as an appendix. Overall, this report focuses on each cloud provider's performance scores and respective value when stacked up against their competitors. For this analysis, Cloud Spectator tested two block storage volume sizes for each VM to get a detailed look at storage performance, and compared two popular Linode Shared and Dedicated plans to comparable offerings from other providers.

This analysis includes the following providers: Linode, Amazon Web Services (AWS), Microsoft Azure (Azure), Google Cloud Platform (GCP), Vultr, and DigitalOcean. All testing was performed in a North American data center for each provider.

Highlights from this analysis include:

- Linode's latest NVMe-based Block Storage offering displays excellent read and write performance compared to all other providers tested. **In performance per dollar, Linode outperformed the next closest provider by 30% or more.**
- **Linode continues to offer high performance VM CPUs and storage at a lower cost than most providers in this analysis.**
- Linode's small **1-CPU VM offers the best CPU, storage, and database performance in its class.**
- Linode's **4-CPU dedicated VM and NVMe Block Storage significantly outperforms dedicated or CPU optimized plans from other providers in database performance tests**, as well as being a top performer and leader in price-performance.

The remainder of this report presents the selection and testing methodology along with results of the benchmarking effort.

Testing Methodology

All VMs went through the exact same setup process, which involved updating all packages and then rebooting, followed by entire disk partitioning (if needed). Each VM was left alone for one hour after mounting each storage device to allow the operating system to initialize the filesystem (via ext4lazyinit). Each VM was tested “as is” with no kernel or operating system optimizations applied.

Test Design Considerations

Infrastructure performance testing was conducted on specific VM and storage types for each provider. VM configurations can yield different results based on underlying infrastructure, time of day, number of tenants running other workloads on the same hardware, virtualization technology and settings (e.g. shared resources), and other factors.

Furthermore, issues such as user contention or physical hardware malfunctions can also cause suboptimal performance. The VMs and storage volumes selected for this engagement were generally available with specified offerings from the various providers unless otherwise noted in the charted results.

Infrastructure Testing: CPU

Compute results were obtained using the GeekBench5 benchmarks. GeekBench5 was performed with standard/default testing options.

Infrastructure Testing: Block Storage

Storage results were obtained using FIO (Flexible I/O tester) using 4KB block size and a total job/thread count that matches each VM's vCPU count. Multiple 300-second iterations were conducted to compensate for the high variability often seen when stressing storage volumes. Results were gathered and represented in IOPs (input/output operations per second). The results displayed in this report are derived from the average IOP value recorded during each test.

Infrastructure Testing: Database

Database results were obtained using the Sysbench OLTP read/write database test. A single database with more than 1 million rows was generated on each VM. The latest version of MySQL was installed on each server and the main configuration file was replaced on all VMs to ensure the exact same configuration settings were used.

4-CPU Dedicated VMs > Plan Specifications & Pricing

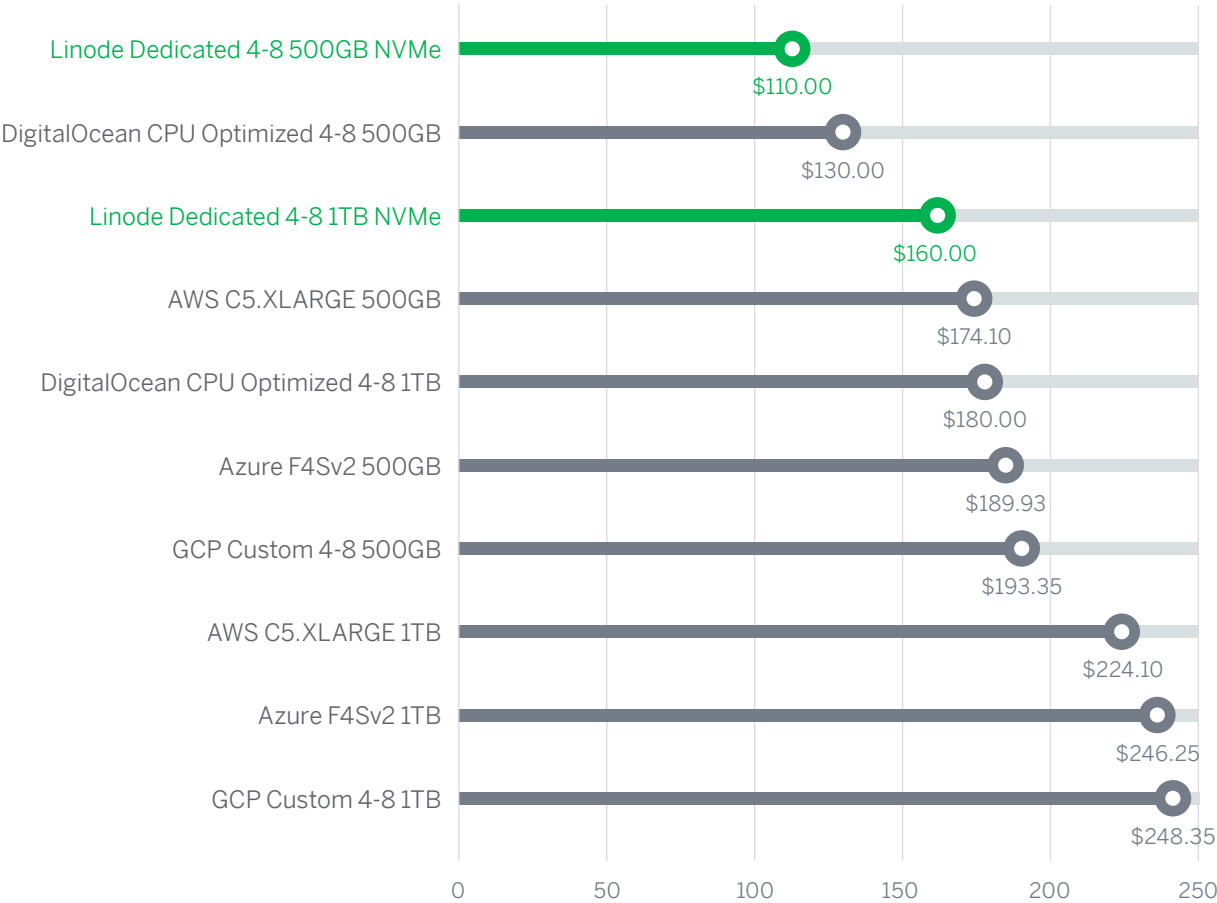
The first group consists of 4-CPU VMs that have dedicated or CPU optimized cores. The 4-CPU group uses a 500GB volume as well as a 1TB volume. Dedicated CPUs are the best choice for applications that have critical performance requirements, high traffic, or otherwise need to avoid potential negative impact from “noisy neighbors” in a shared environment. At the time of this report, some providers did not have comparable dedicated CPU plans, and are omitted from these results.

4-CPU Dedicated VM & Block Storage Plans

VM	Location	CPU Count	RAM	Storage	Storage Size	VM Hourly	Storage Hourly	Total Hourly	Total Monthly
AWS C5.XLARGE 1TB	US EAST	4	8	Block Storage	1TB	\$0.170	\$0.137	\$0.31	\$224.10
AWS C5.XLARGE 500GB	US EAST	4	8	Block Storage	500GB	\$0.170	\$0.068	\$0.24	\$174.10
Azure F4Sv2 1TB	US EAST	4	8	Block Storage	1TB	\$0.169	\$0.168	\$0.34	\$246.25
Azure F4Sv2 500GB	US EAST	4	8	Block Storage	500GB	\$0.169	\$0.091	\$0.26	\$189.93
DigitalOcean CPU Optimized 4-8 1TB	US EAST	4	8	Block Storage	1TB	\$0.110	\$0.137	\$0.25	\$180.00
DigitalOcean CPU Optimized 4-8 500GB	US EAST	4	8	Block Storage	500GB	\$0.110	\$0.068	\$0.18	\$130.00
GCP Custom 4-8 1TB	US EAST	4	8	Block Storage Balanced	1TB	\$0.190	\$0.151	\$0.34	\$248.35
GCP Custom 4-8 500GB	US EAST	4	8	Block Storage Balanced	500GB	\$0.190	\$0.075	\$0.26	\$193.35
Linode Dedicated 4-8 1TB NVMe	US EAST	4	8	Block Storage	1TB	\$0.082	\$0.137	\$0.22	\$160.00
Linode Dedicated 4-8 500GB NVMe	US EAST	4	8	Block Storage	500GB	\$0.082	\$0.068	\$0.15	\$110.00

4-CPU Dedicated VMs > Plan Specifications & Pricing

\$ 4-CPU Dedicated VMs - Total Monthly Cost

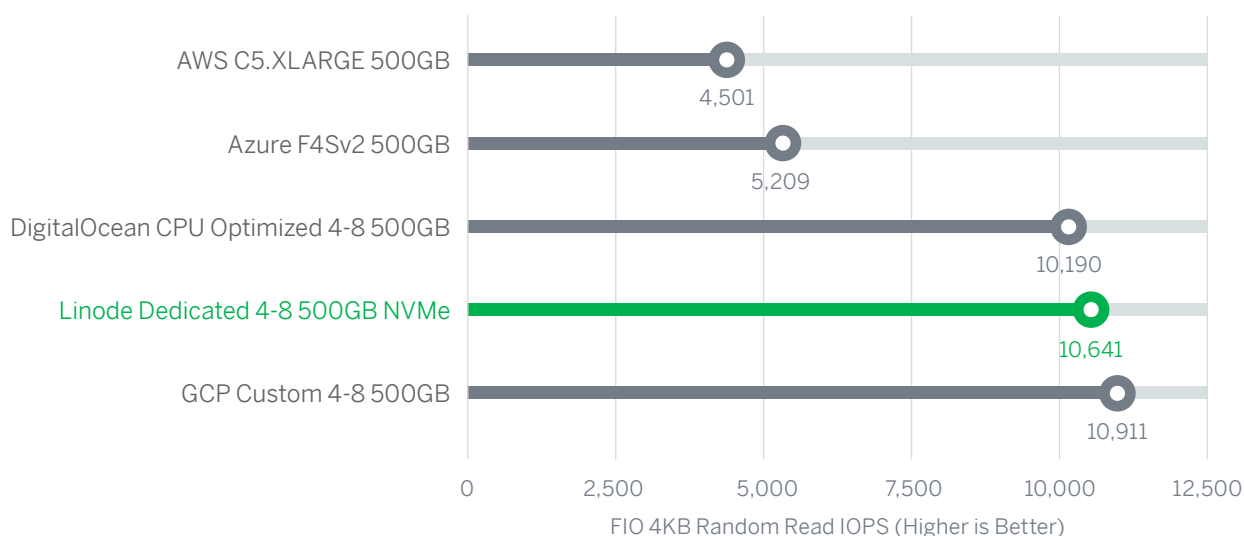


4-CPU Dedicated > Block Storage IOPS Analysis > Read

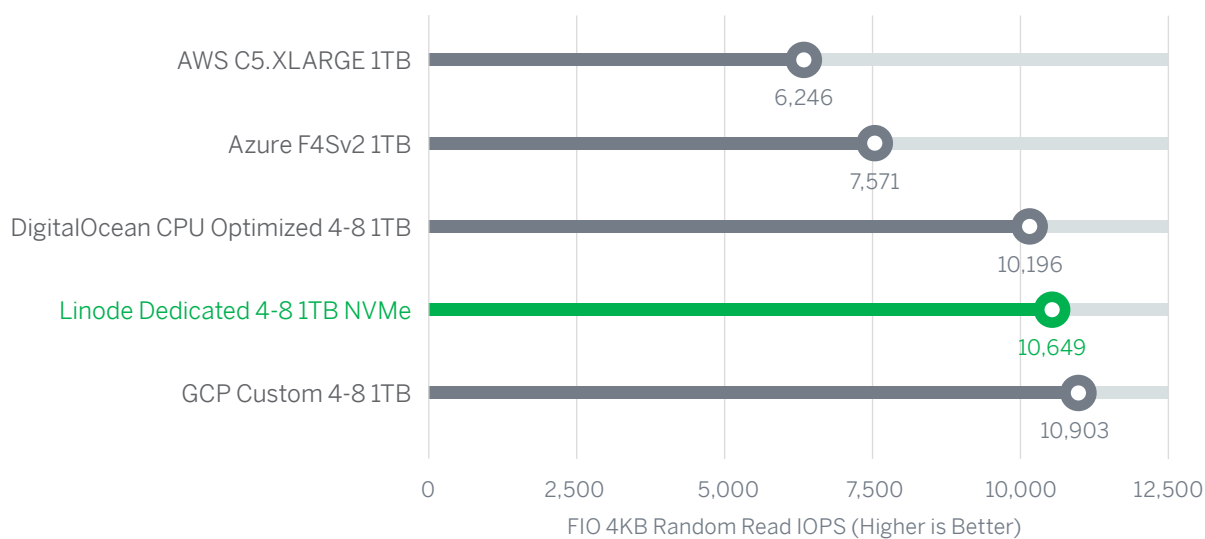
Block Storage IOPS Analysis

For both the 500GB and 1TB volume sizes, Linode's NVMe Block Storage offered a very close second fastest read performance for both volume sizes after GCP. DigitalOcean finished in third place. There's a significant difference in performance between the leaders and the other providers.

★ Dedicated VMs (4 CPUs) & 500GB Block Storage - 4K Storage AVG READ IOPS



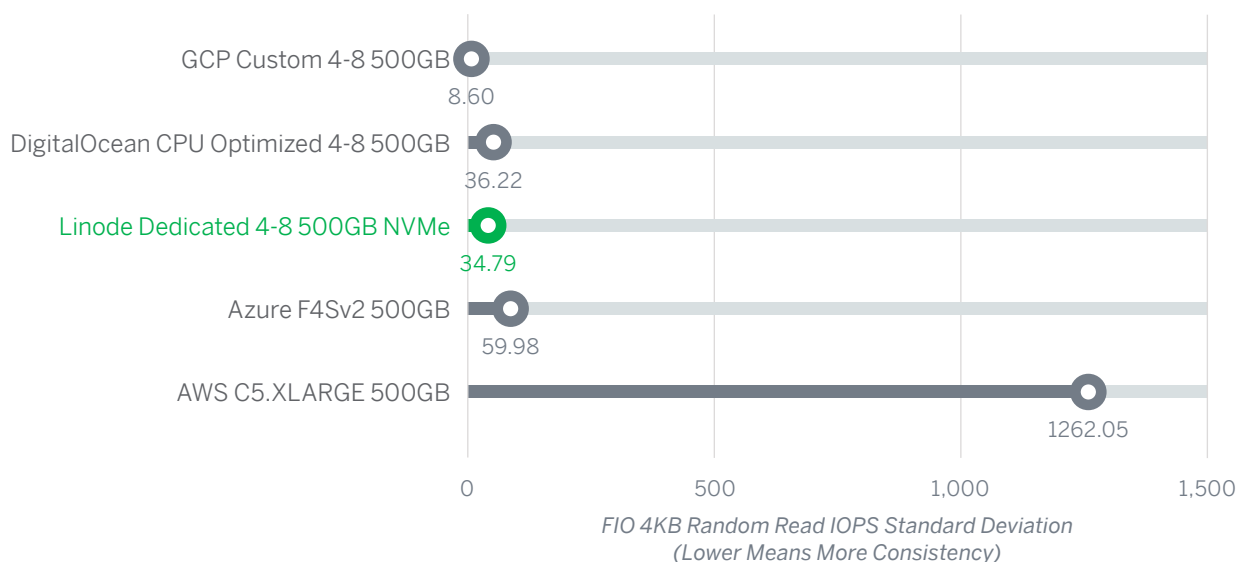
★ Dedicated VMs (4 CPUs) & 1TB Block Storage - 4K Storage AVG READ IOPS



4-CPU Dedicated > Block Storage IOPS Analysis > Read

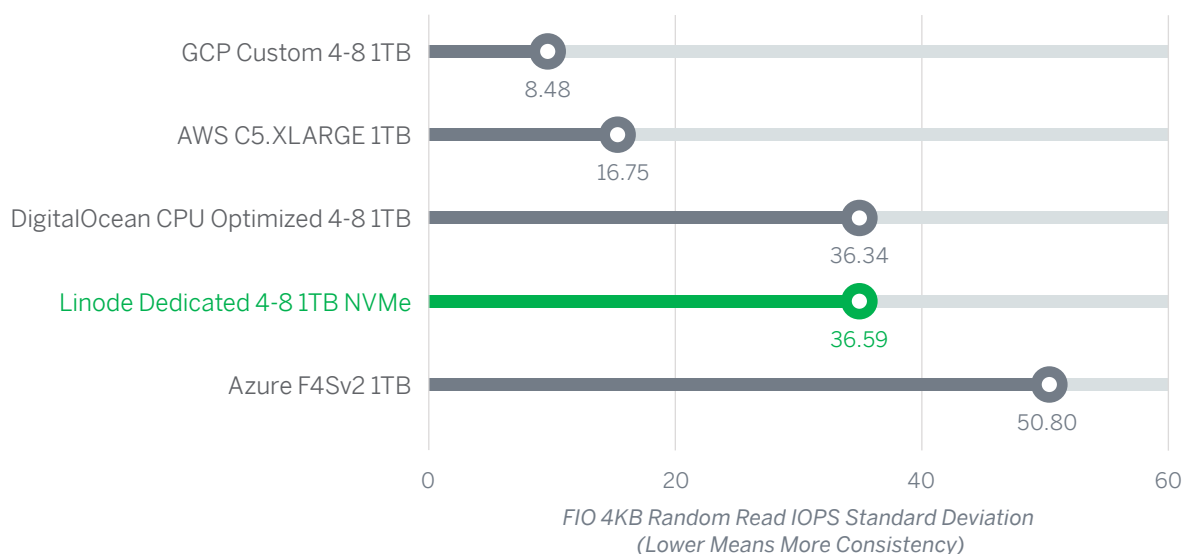
GCP tends to offer more consistent storage performance than the other providers. However, the performance variation for most providers in the 500GB volume group is rather low except for AWS.

★ Dedicated VMs (4 CPUs) & 500GB Block Storage - 4K Storage READ - StdDev



For the 1TB volume size, the results are much closer. GCP still showed the most consistency alongside the 500GB volume size. DigitalOcean and Linode ended up in the middle of the pack with almost the exact same score.

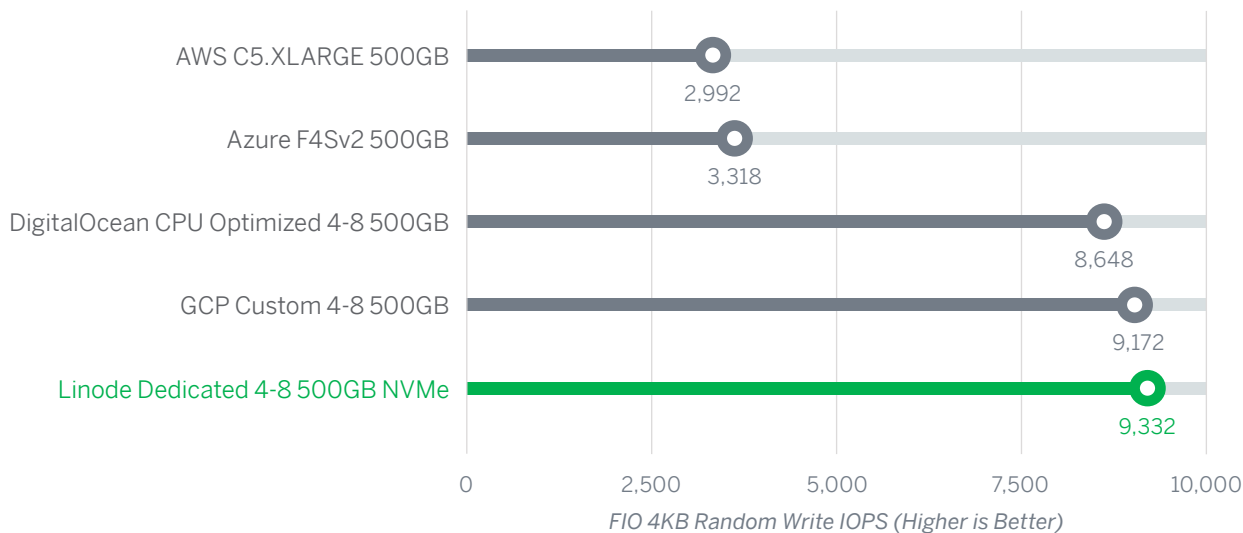
★ Dedicated VMs (4 CPUs) & 1TB Block Storage - 4K Storage READ - StdDev



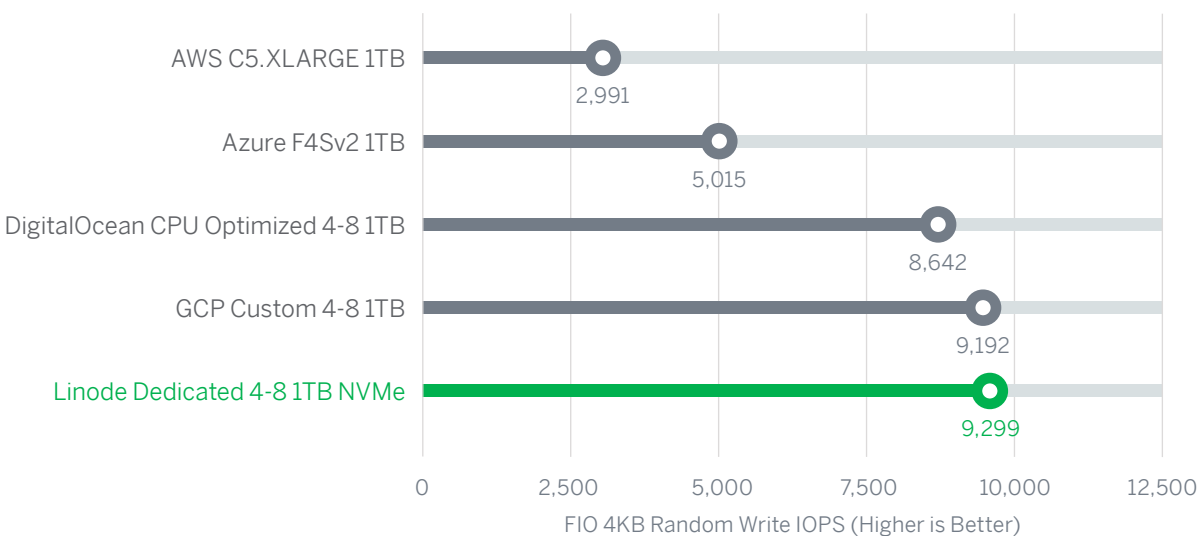
4-CPU Dedicated > Block Storage IOPS Analysis > Write

Linode leads in random write performance, beating all other providers in the 4-CPU VM group for both volume sizes, beating last place AWS by more than triple. GCP is a close second, followed by DigitalOcean.

★ Dedicated VMs (4 CPUs) & 500GB Block Storage - 4K Storage AVG Write IOPS



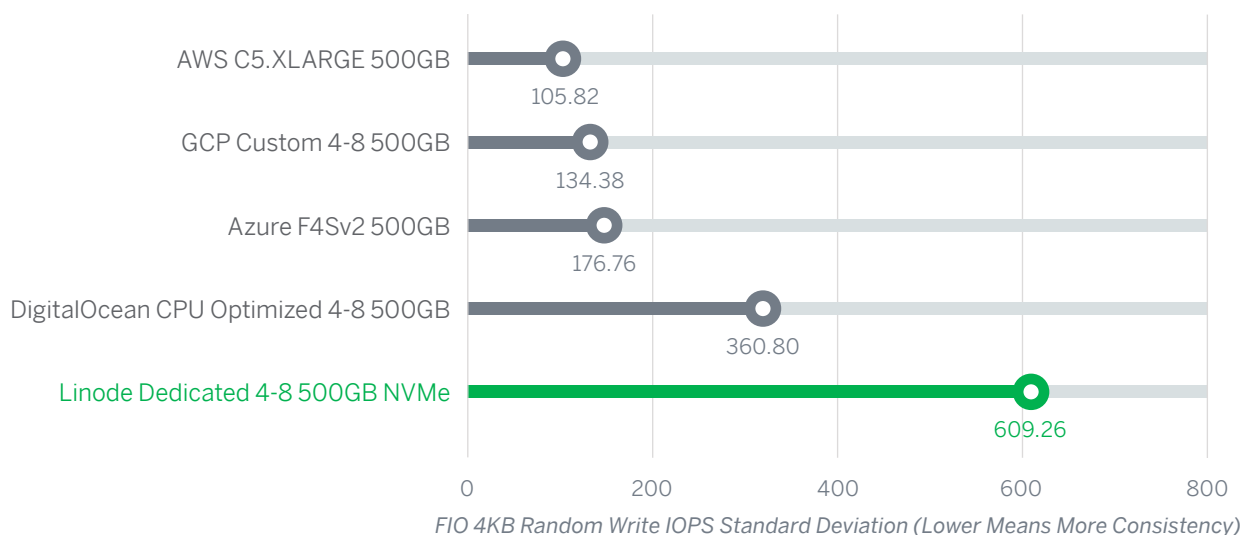
★ Dedicated VMs (4 CPUs) & 1TB Block Storage - 4K Storage AVG Write IOPS



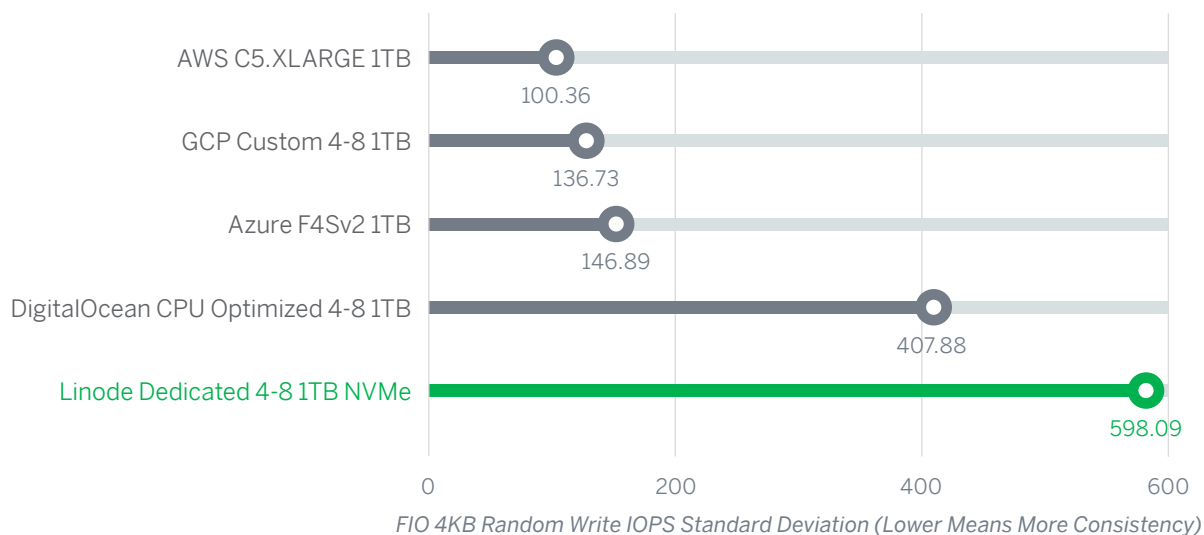
4-CPU Dedicated > Block Storage IOPS Analysis > Write

AWS, GCP, and Azure take the top spots for random write performance consistency, while Linode displayed more inconsistent performance.

★ Dedicated VMs (4 CPUs) & 500GB Block Storage - 4K Storage Write IOPS - StdDev



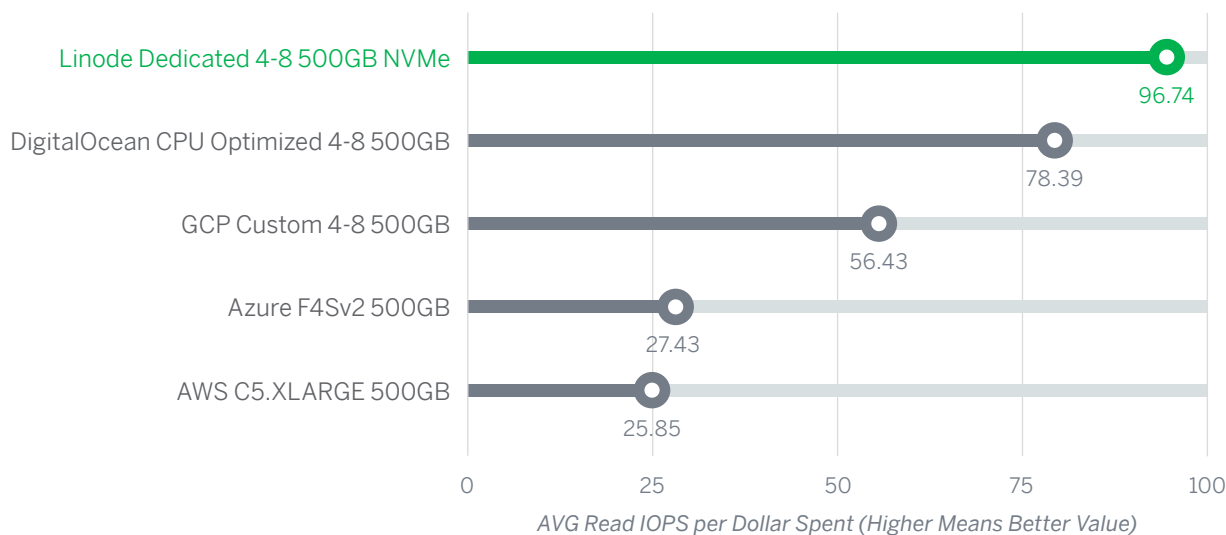
★ Dedicated VMs (4 CPUs) & 1TB Block Storage - 4K Storage Write - StdDev



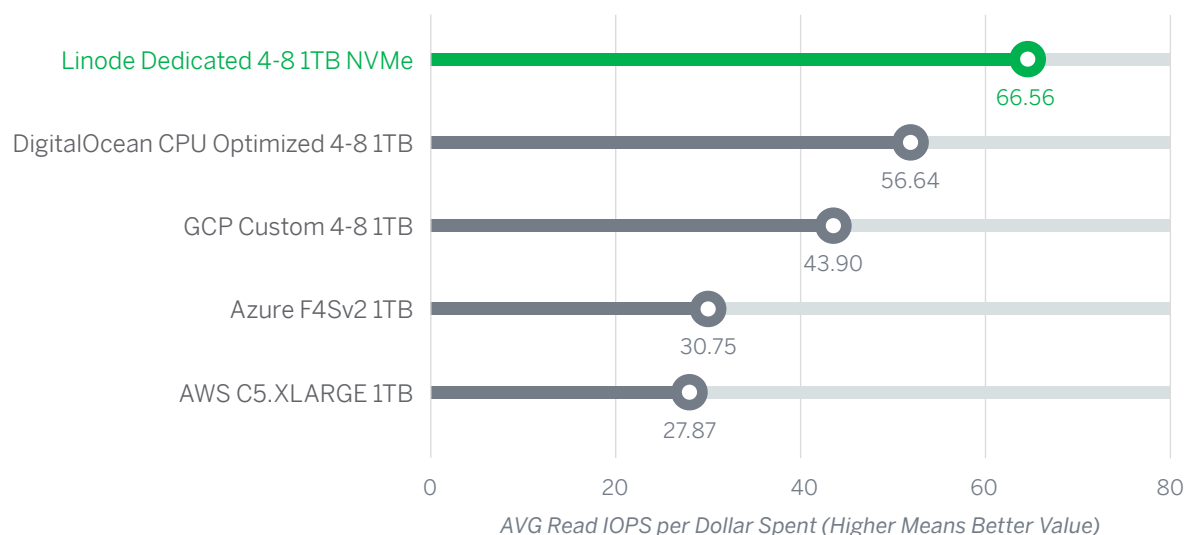
4-CPU Dedicated > Block Storage IOPS Analysis > Read

Linode has a significant lead in terms of random read IOPS per dollar spent, beating DigitalOcean by more than 18 IOPs per dollar in the 500GB volume group. GCP lands in the middle of the pack, and Azure and AWS show very similar value per dollar.

\$ Dedicated VMs (4 CPUs) & 500GB Block Storage - 4K Storage READ IOPS per Dollar



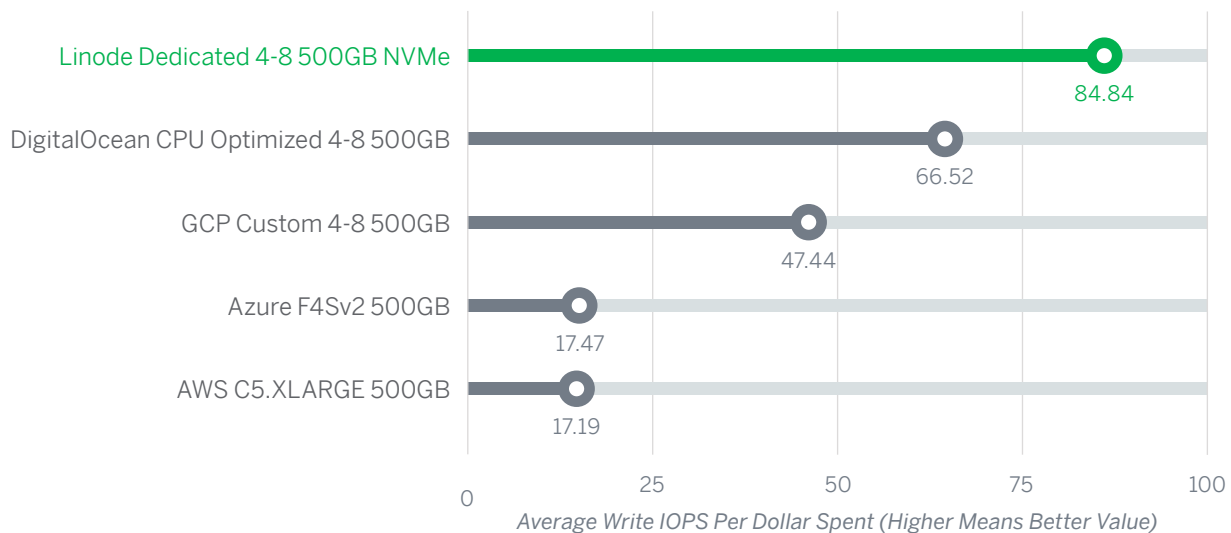
\$ Dedicated VMs (4 CPUs) & 1TB Block Storage - 4K Storage READ IOPS per Dollar



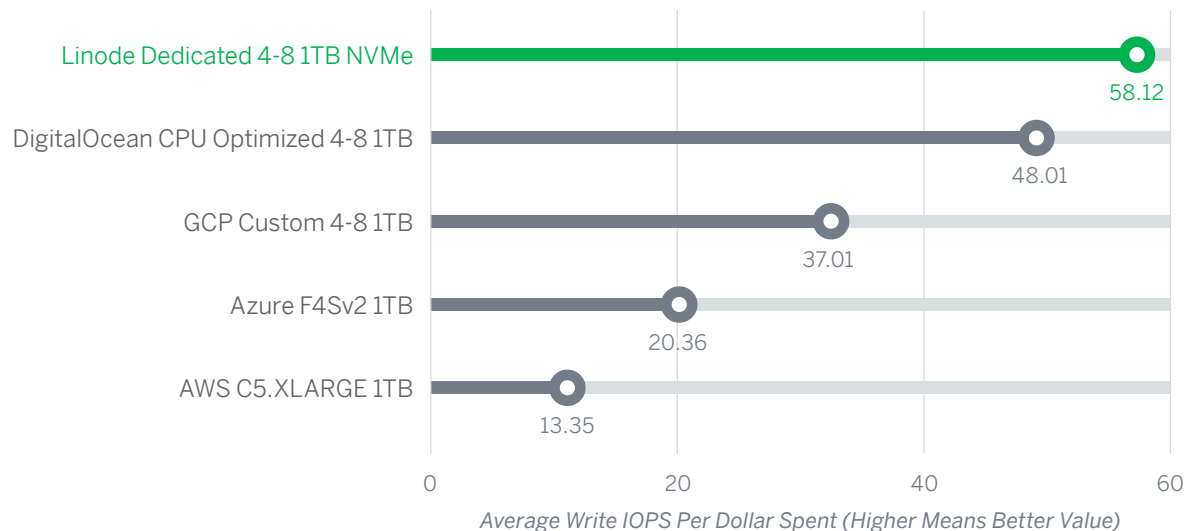
4-CPU Dedicated > Block Storage IOPS Analysis > Write

Results for random write performance per dollar spent are similar. Linode is the leader and beats DigitalOcean by 18 IOPS per dollar.

\$ Dedicated VMs (4 CPUs) & 500GB Block Storage - 4K Storage Write IOPS per Dollar



\$ Dedicated VMs (4 CPUs) & 1TB Block Storage - 4K Storage Write IOPS per Dollar

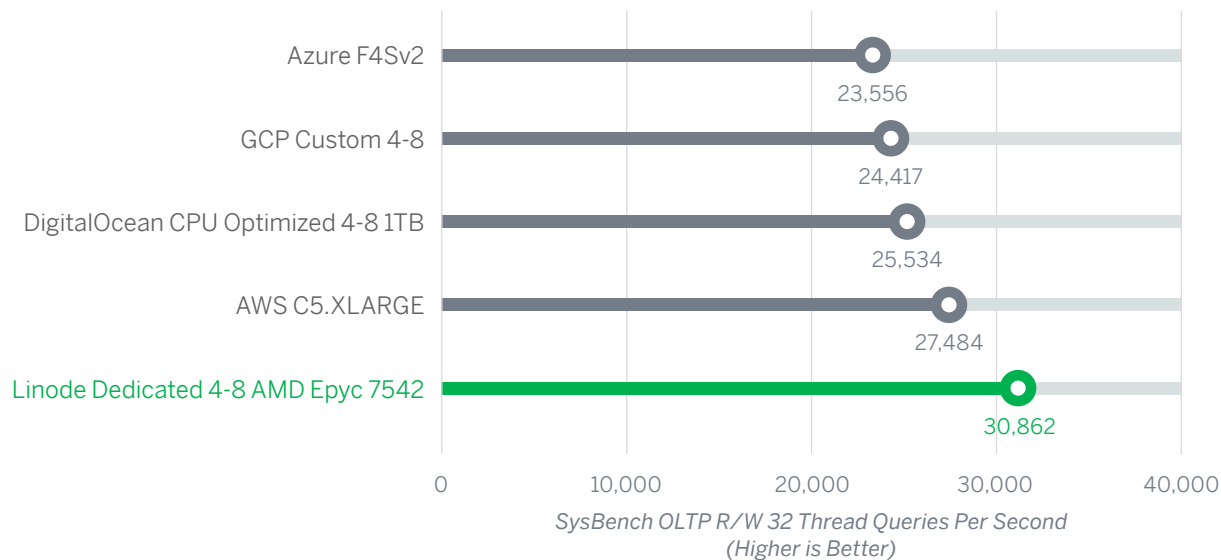


4-CPU Dedicated > Database Performance > OLTP Queries Per Second

Database Performance

Linode offers the best production database performance in the Dedicated group with a significant lead over AWS.

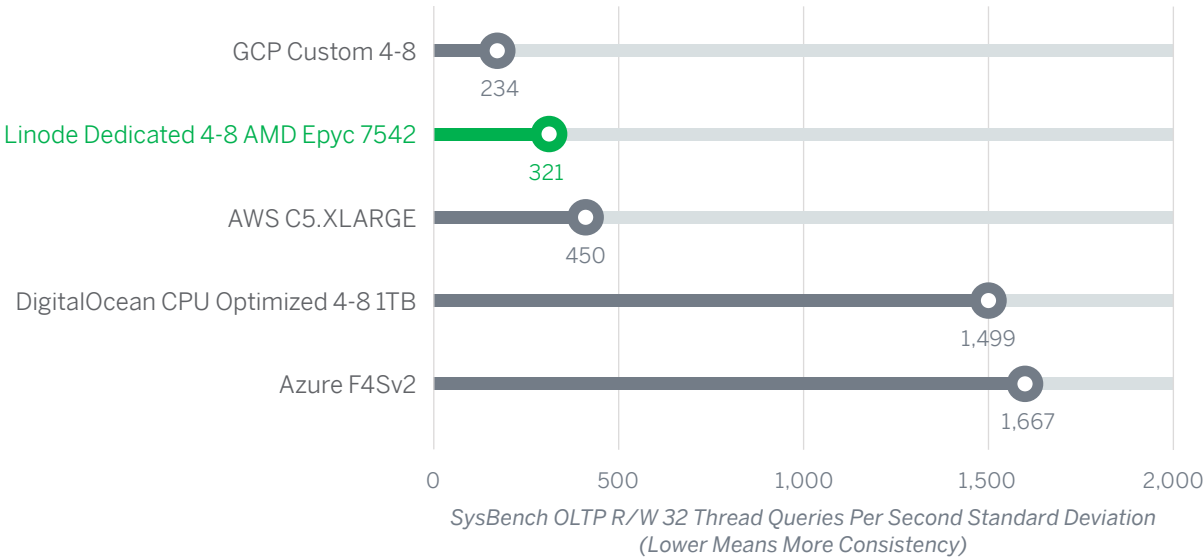
★ Dedicated VMs (4 CPUs) - OLTP Average Queries Per Second



4-CPU Dedicated > Database Performance > OLTP Queries Per Second

GCP, Linode, and AWS take the top spots for most consistent database performance. DigitalOcean and Azure showed similar results and are behind the leaders in this category.

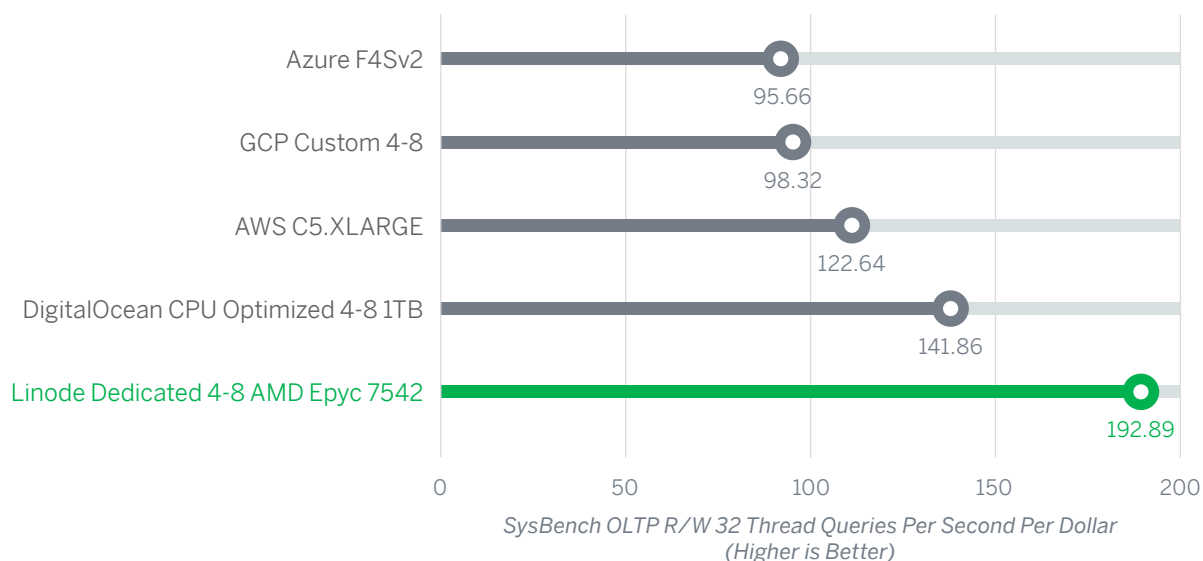
☆ 4-CPU VMs - OLTP Queries Per Second StdDev



4-CPU Dedicated > Database Performance > OLTP Queries Price-Performance

The second VM size in this analysis consists of 1-CPU VMs running in a shared CPU environment. The 1-CPU group uses two smaller block storage volume sizes, 100GB and 500GB. Shared VMs are ideal for smaller workloads including websites or applications with low traffic, test environments, and provisioning multiple machines for services like security penetration testing.

💰 4-CPU VMs - OLTP Queries Per Second Per Dollar



1-CPU Shared VMs > Plan Specifications & Pricing

The second VM size in this analysis consists of 1-CPU VMs running in a shared CPU environment. The 1-CPU group uses two smaller block storage volume sizes, 100GB and 500GB. Shared VMs are ideal for smaller workloads including websites or applications with low traffic, test environments, and provisioning multiple machines for services like security penetration testing.

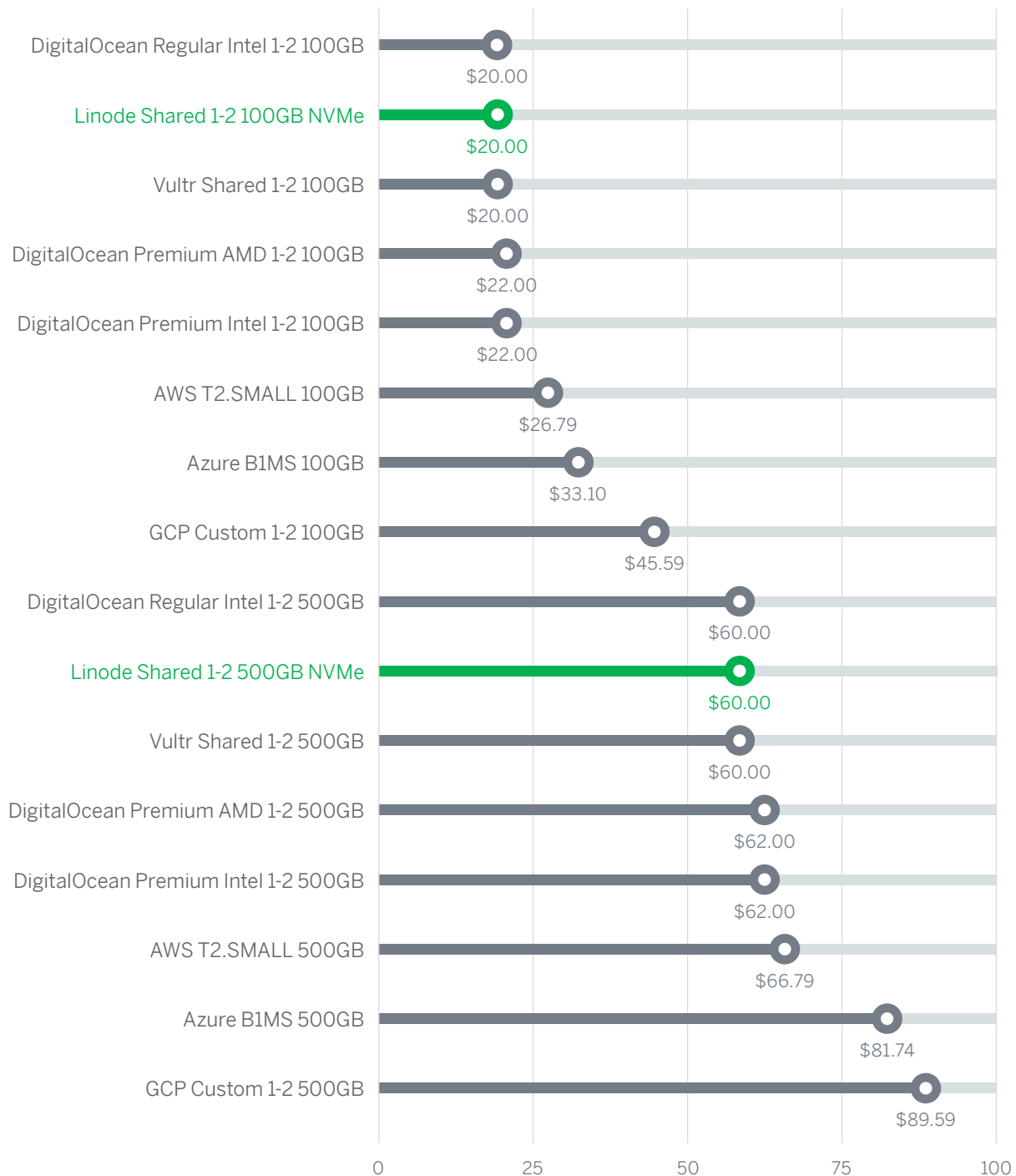
1-CPU Shared VMs > Plan Specifications & Pricing

1-CPU VM & Block Storage Plans

VM	Location	CPU Count	RAM	Storage	Storage Size	VM Hourly	Storage Hourly	Total Hourly	Total Monthly
AWS T2.SMALL 100GB	US EAST	1	2	Block Storage	100GB	\$0.023	\$0.014	\$0.04	\$26.79
AWS T2. SMALL 500GB	US EAST	1	2	Block Storage	500GB	\$0.023	\$0.068	\$0.09	\$66.79
Azure B1MS 100GB	US EAST	1	2	Block Storage	100GB	\$0.021	\$0.025	\$0.05	\$33.10
Azure B1MS 500GB	US EAST	1	2	Block Storage	500GB	\$0.021	\$0.091	\$0.11	\$81.74
DigitalOcean Premium AMD 1-2 100GB	US EAST	1	2	Block Storage	100GB	\$0.016	\$0.014	\$0.03	\$22.00
DigitalOcean Premium AMD 1-2 500GB	US EAST	1	2	Block Storage	500GB	\$0.016	\$0.068	\$0.08	\$62.00
DigitalOcean Premium Intel 1-2 100GB	US EAST	1	2	Block Storage	100GB	\$0.016	\$0.014	\$0.03	\$22.00
DigitalOcean Premium Intel 1-2 500GB	US EAST	1	2	Block Storage	500GB	\$0.016	\$0.068	\$0.08	\$62.00
DigitalOcean Regular Intel 1-2 100GB	US EAST	1	2	Block Storage	100GB	\$0.014	\$0.014	\$0.03	\$20.00
DigitalOcean Regular Intel 1-2 500GB	US EAST	1	2	Block Storage	500GB	\$0.014	\$0.068	\$0.08	\$60.00
GCP Custom 1-2 100GB	US EAST	1	2	Block Storage Balanced	100GB	\$0.047	\$0.015	\$0.06	\$45.59
GCP Custom 1-2 500GB	US EAST	1	2	Block Storage Balanced	500GB	\$0.047	\$0.075	\$0.12	\$89.59
Linode Shared 1-2 100GB NVMe	US EAST	1	2	Block Storage	100GB	\$0.014	\$0.014	\$0.03	\$20.00
Linode Shared 1-2 500GB NVMe	US EAST	1	2	Block Storage	500GB	\$0.014	\$0.068	\$0.08	\$60.00
Vultr Shared 1-2 100GB	US EAST	1	2	Block Storage	100GB	\$0.014	\$0.014	\$0.03	\$20.00
Vultr Shared 1-2 500GB	US EAST	1	2	Block Storage	500GB	\$0.014	\$0.068	\$0.08	\$60.00
Vultr Shared 1-2 100GB NVMe	US EAST	1	2	NVMe Block Storage (Beta)	100GB	\$0.014	\$0.014	\$0.03	\$20.00
Vultr Shared 1-2 500GB NVMe	US EAST	1	2	NVMe Block Storage (Beta)	500GB	\$0.014	\$0.068	\$0.08	\$60.00

1-CPU Shared VMs > Plan Specifications & Pricing

\$ 1-CPU Shared VMs - Total Monthly Cost

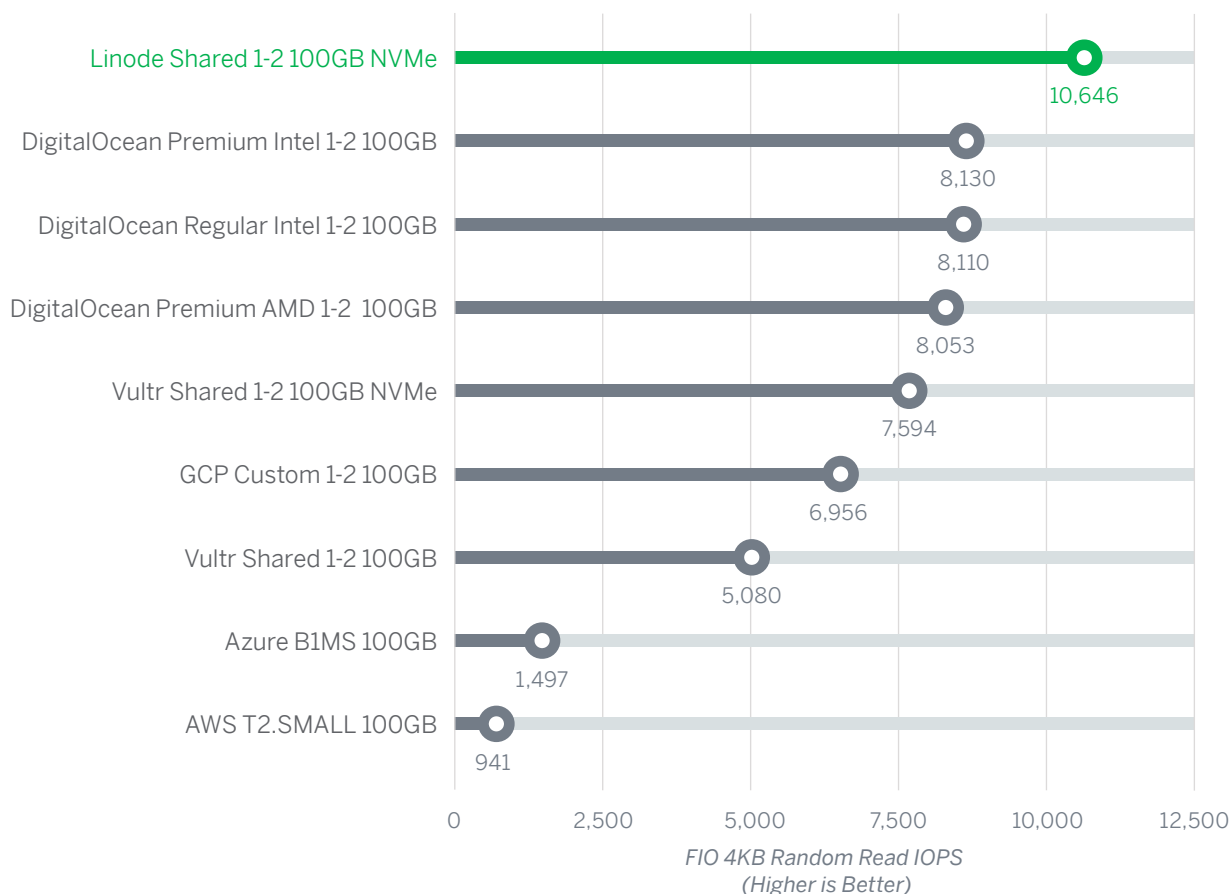


1-CPU Shared > Block Storage IOPS Analysis > Read

Block Storage IOPS Analysis

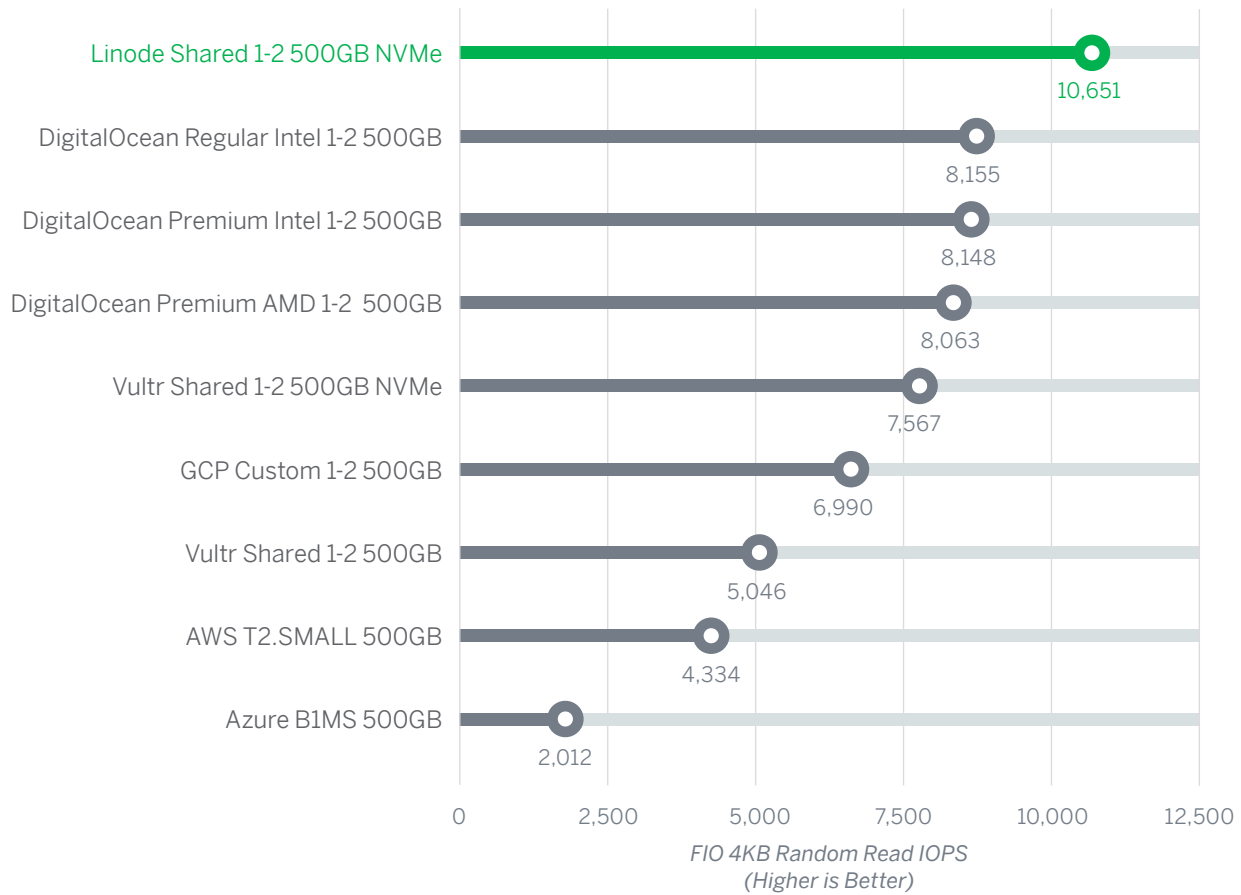
Linode's latest NVMe Block Storage beats all other offerings by a significant amount in read performance. In this case, Linode offers 30% better random read performance than DigitalOcean and over 10x better read performance than AWS EBS when using the 100GB volume size.

★ Shared VMs (1 CPU) & 100GB Block Storage - 4K Storage AVG READ IOPS



1-CPU Shared > Block Storage IOPS Analysis > Read

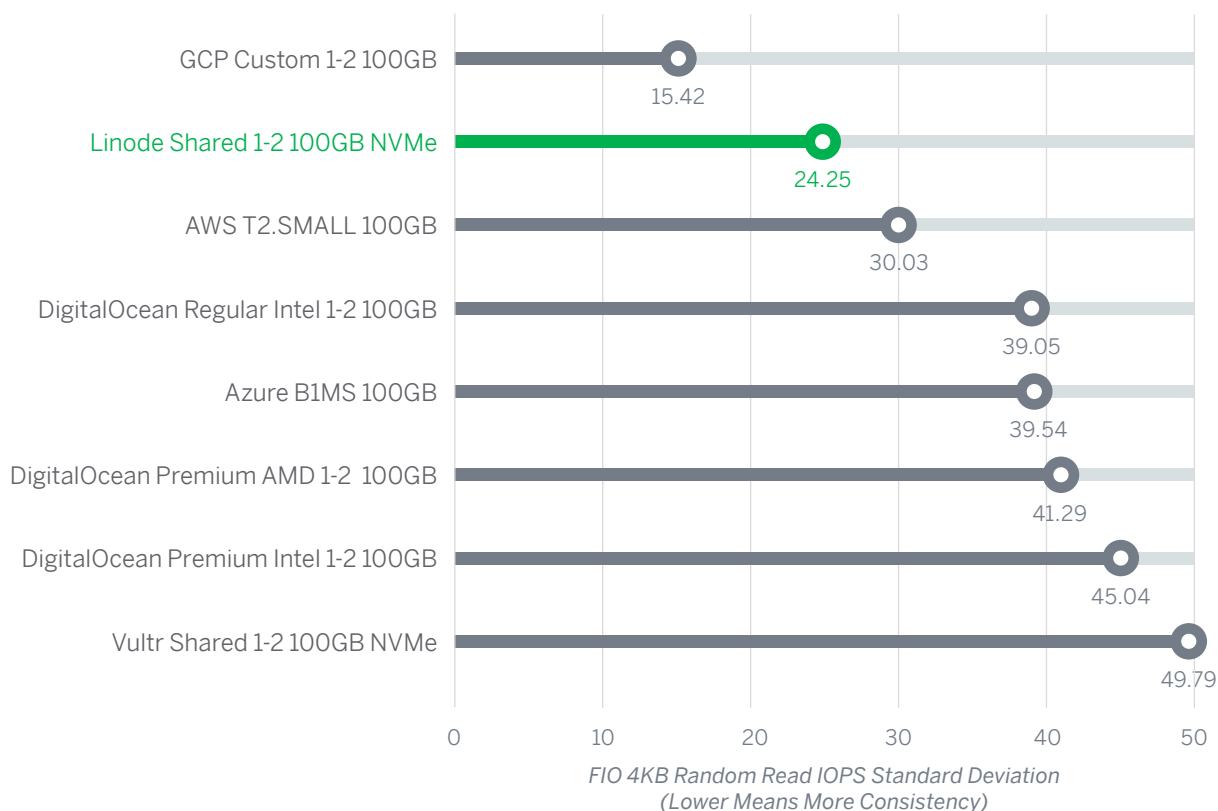
★ Shared VMs (1 CPU) & 500GB Block Storage - 4K Storage AVG READ IOPS



1-CPU Shared > Block Storage IOPS Analysis > Read

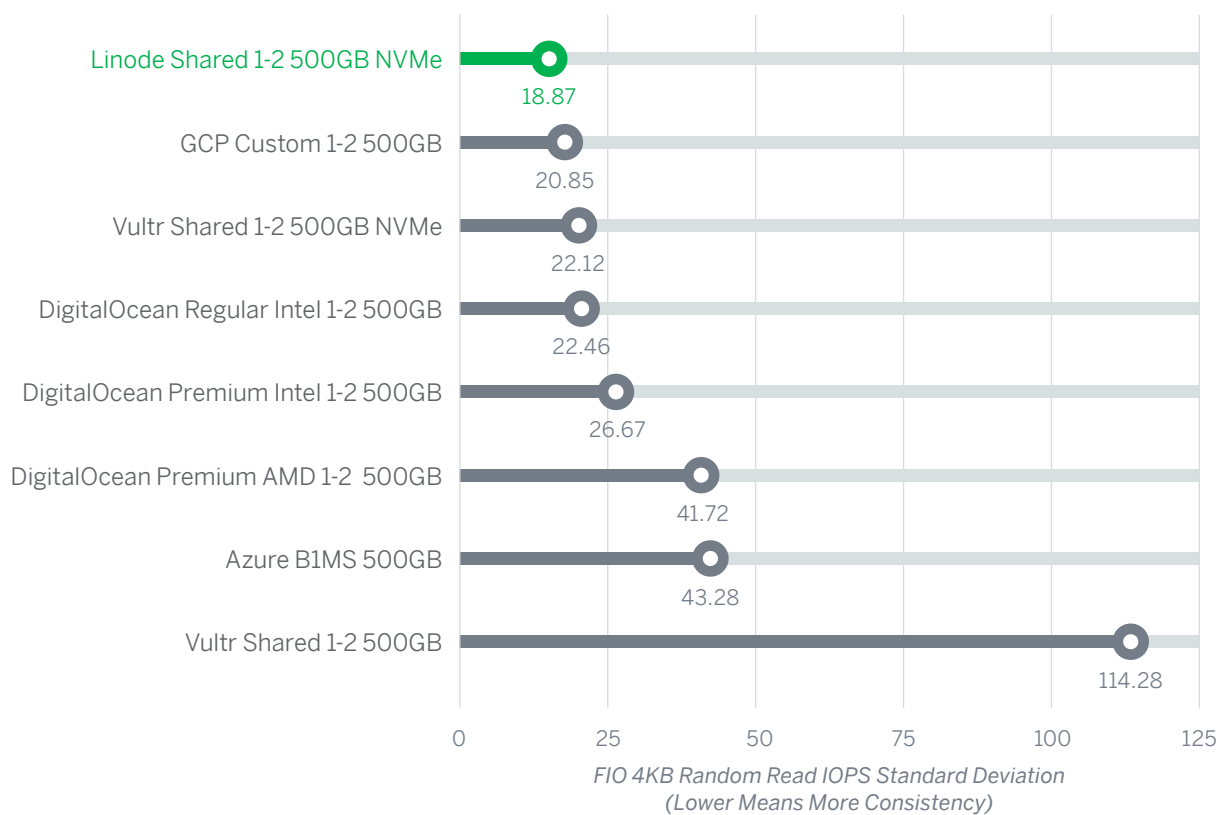
Looking at random read performance consistency, GCP and Linode offer the most consistent random read performance for both volume size groups. Vultr's beta NVMe block storage showed the worst performance in the 100GB volume size group, but performed significantly better in the 500GB volume group.

★ Shared VMs (1 CPU) & 100GB Block Storage - 4K Storage READ - Std Dev



1-CPU Shared > Block Storage IOPS Analysis > Read

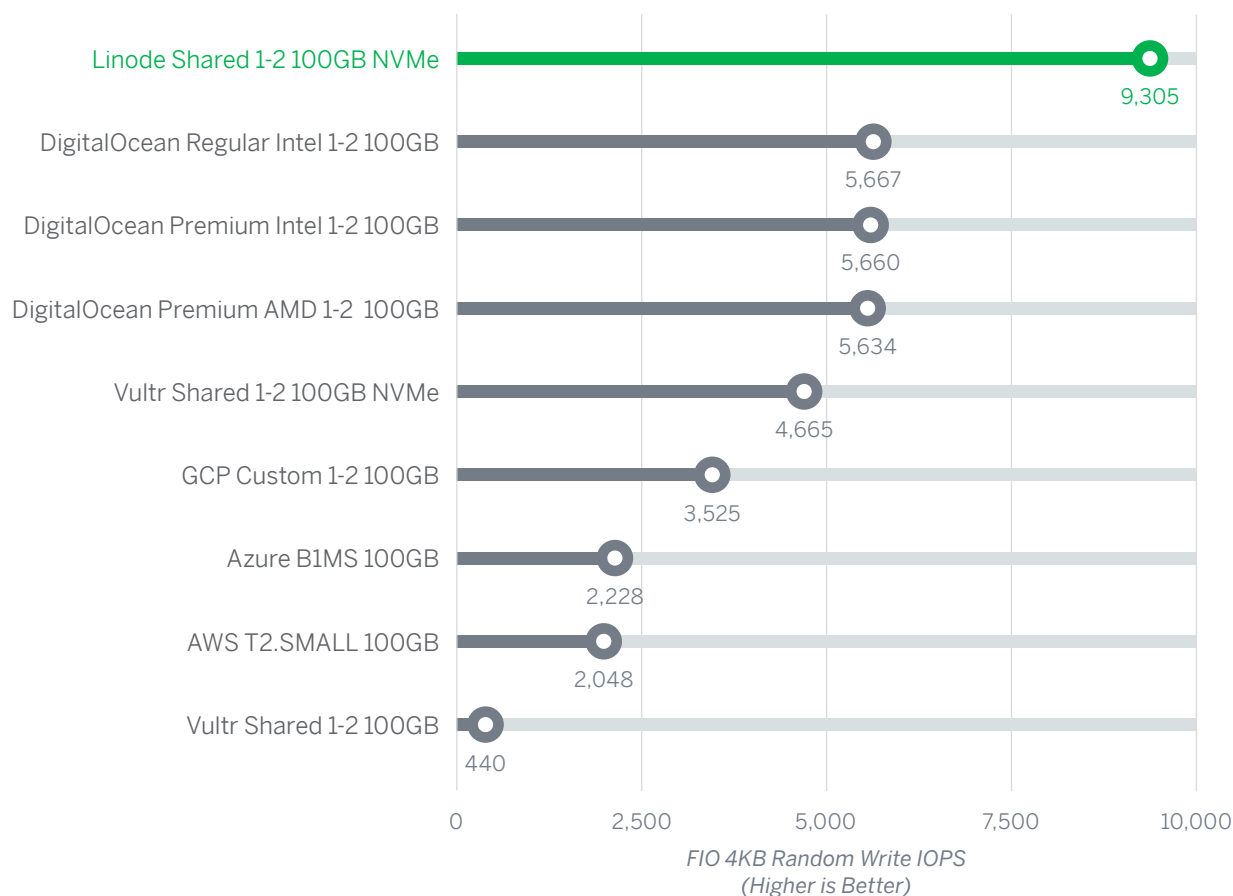
★ Shared VMs (1 CPU) & 500GB Block Storage - 4K Storage READ - Std Dev



1-CPU Shared > Block Storage IOPS Analysis > Write

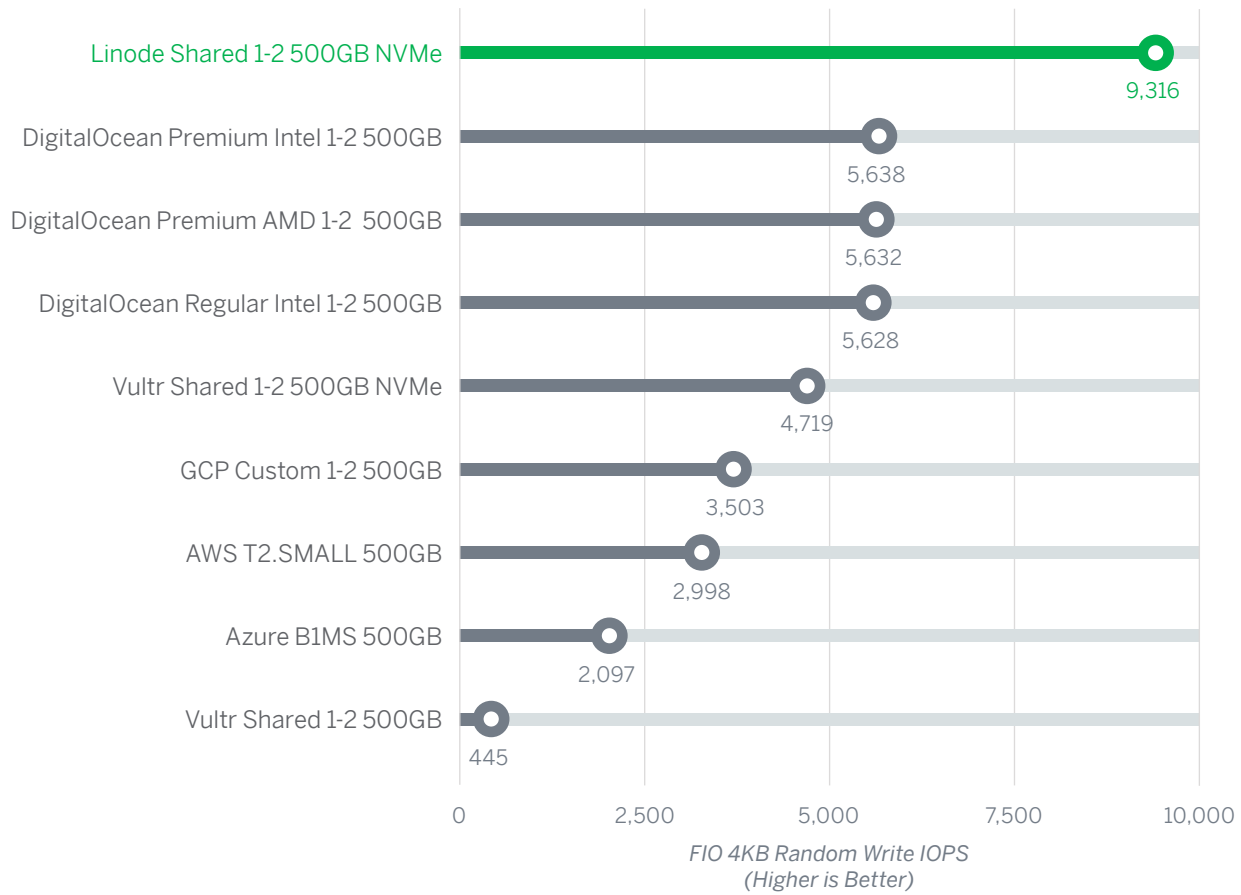
Linode also offers the best random write performance out of all the 1-CPU configurations tested, offering 64% faster random write performance than DigitalOcean and over 4x better performance than AWS's 100GB volume. In this round of tests, DigitalOcean's premium shared Droplets perform alongside its regular Intel-based offering.

★ Shared VMs (1 CPU) & 100GB Block Storage - 4K Storage AVG Write IOPS



1-CPU Shared > Block Storage IOPS Analysis > Write

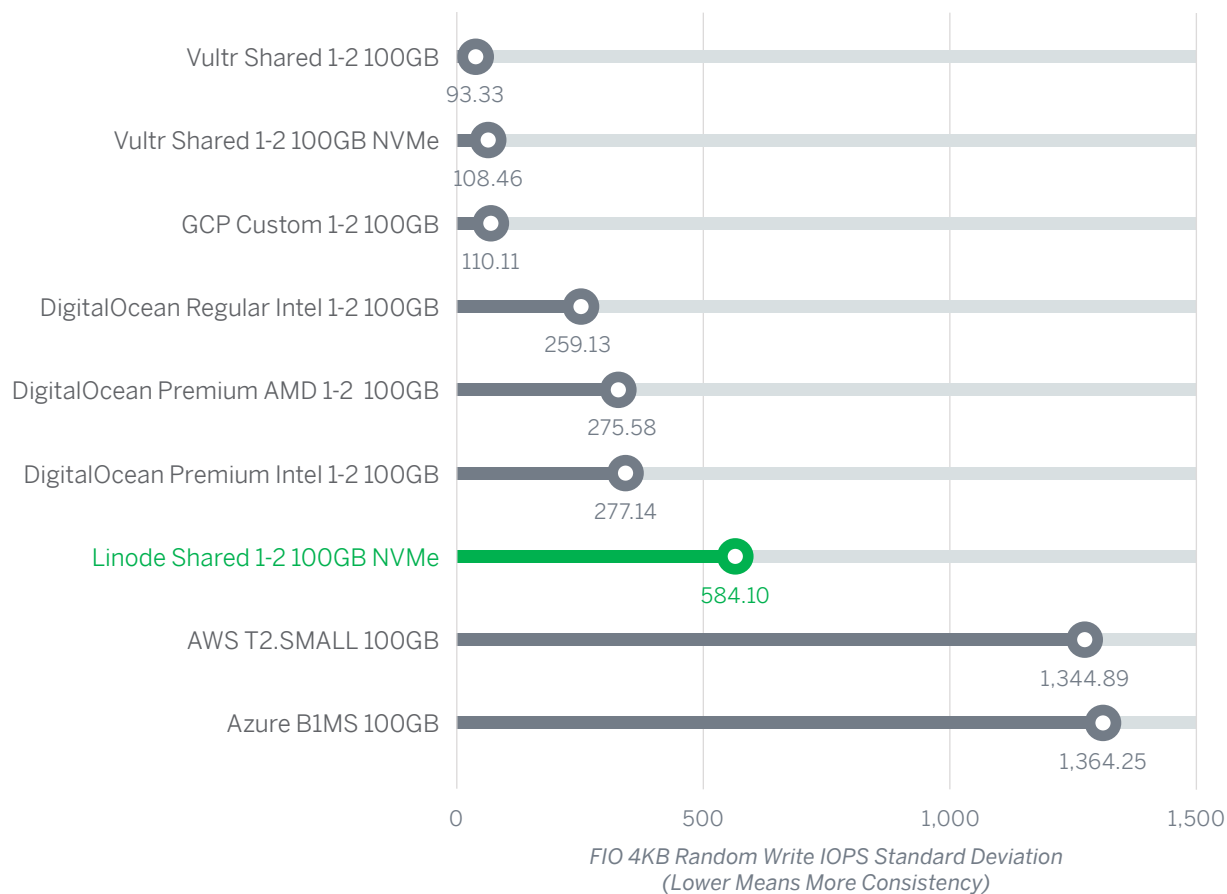
★ Shared VMs (1 CPU) & 500GB Block Storage - 4K Storage AVG Write IOPS



1-CPU Shared > Block Storage IOPS Analysis > Write

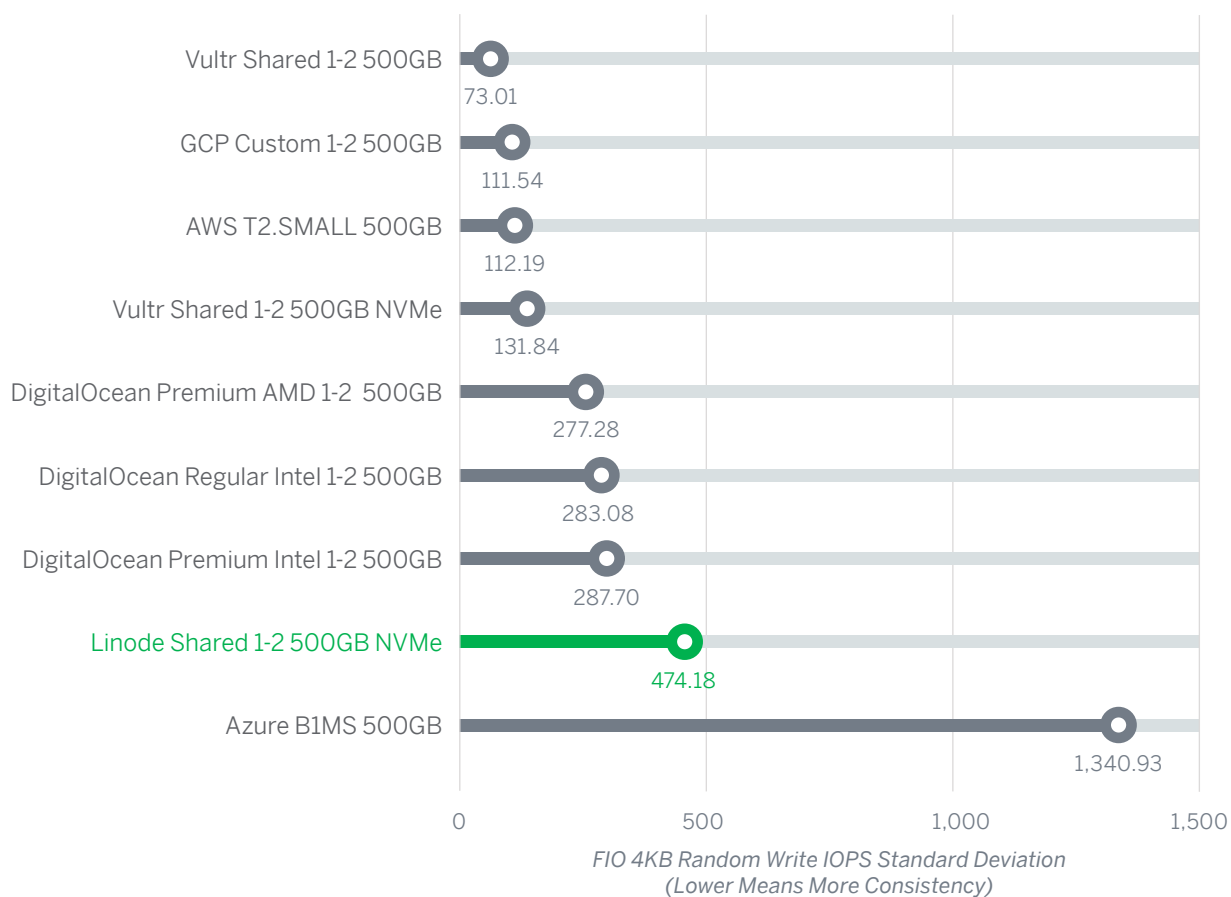
Vultr and GCP did extremely well when measuring consistency for write performance. Linode falls towards the back, but has double the consistency of AWS and Azure.

★ Shared VMs (1 CPU) & 100GB Block Storage - 4K Storage Write - Std Dev



1-CPU Shared > Block Storage IOPS Analysis > Write

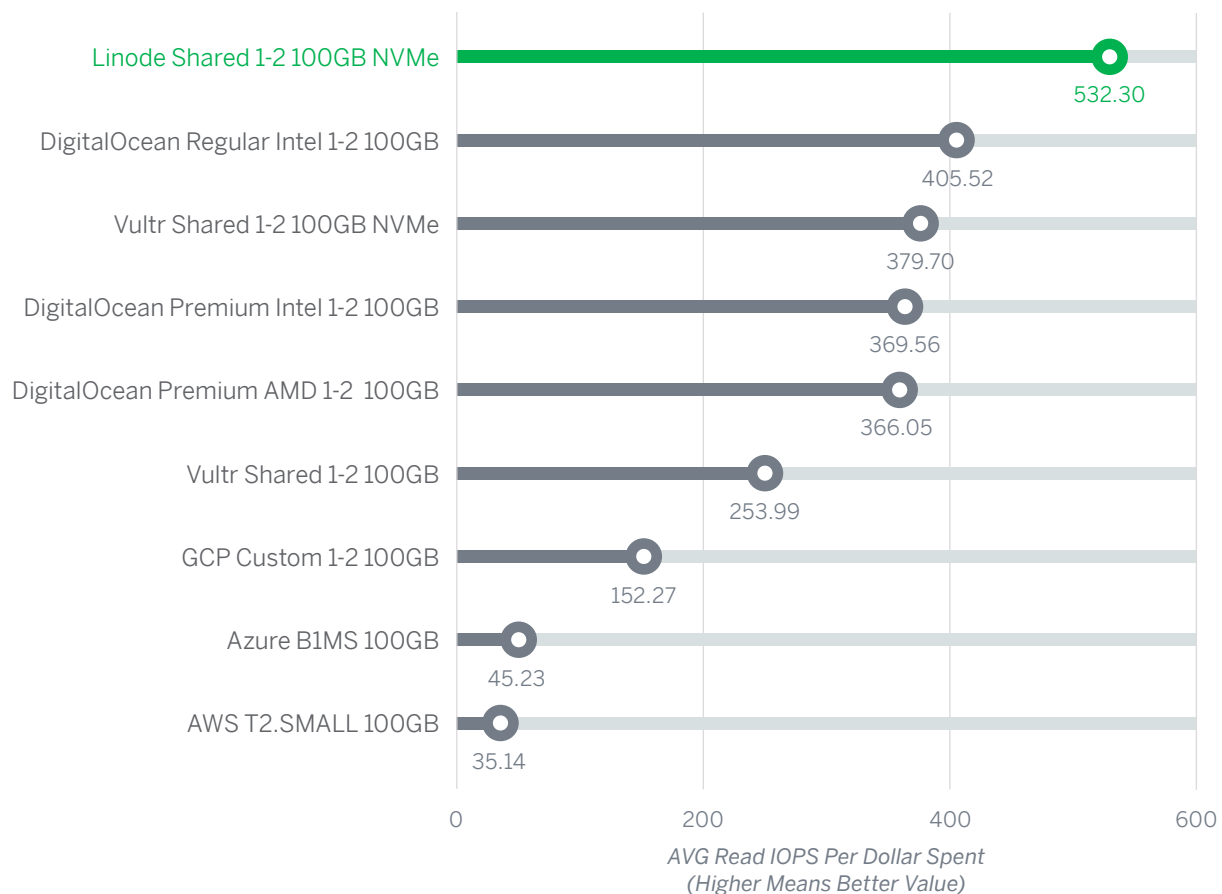
★ Shared VMs (1 CPU) & 500GB Block Storage - 4K Storage Write - Std Dev



1-CPU Shared > Block Storage IOPS Analysis > Price-Performance > Read

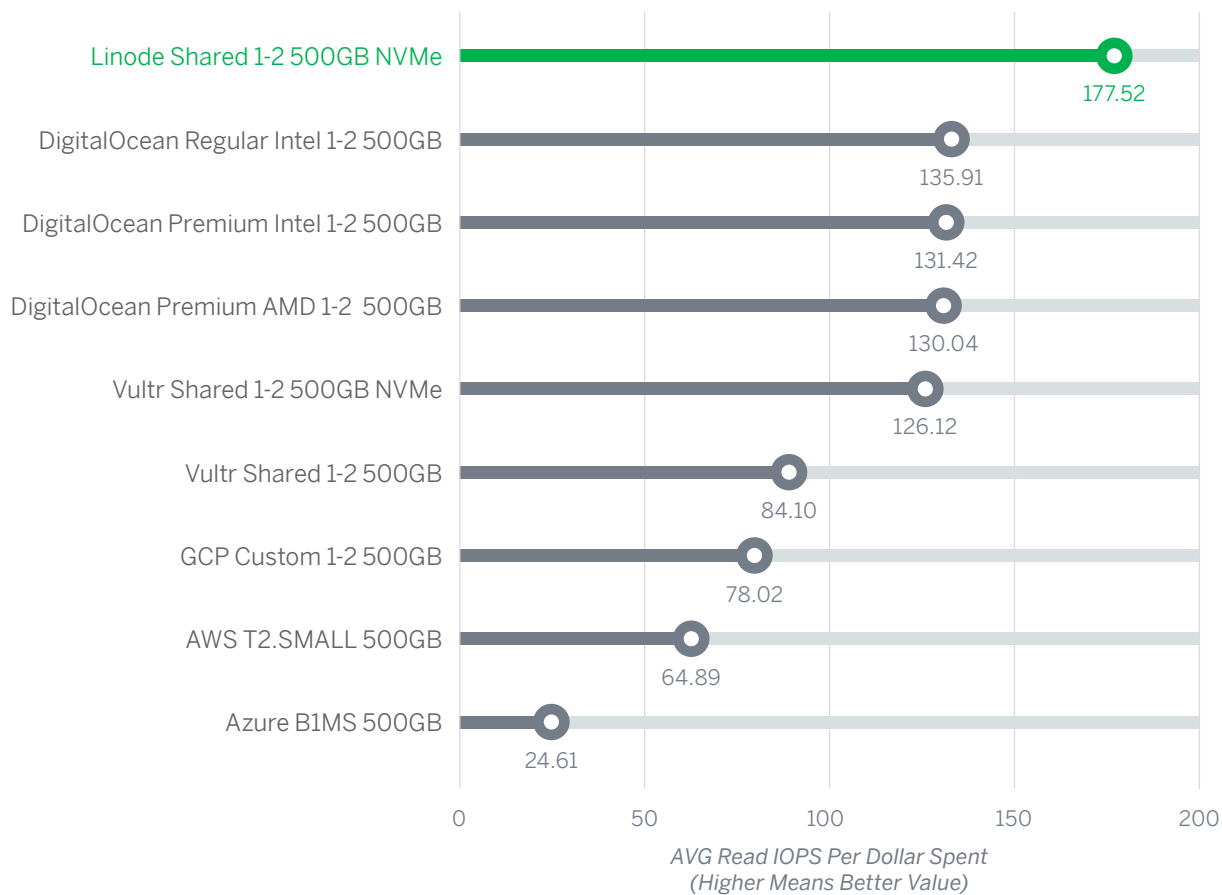
Looking at the Read IOPS per dollar spent, **Linode offers the best random read value** compared to all other providers for both the 500GB and 100GB volume categories, **beating the next closest options by more than 30%**. AWS, GCP, and Azure trail behind when it comes to storage value.

\$ Shared VMs (1 CPU) & 100GB Block Storage - 4K Storage READ IOPS Per Dollar



1-CPU Shared > Block Storage IOPS Analysis > Price-Performance > Read

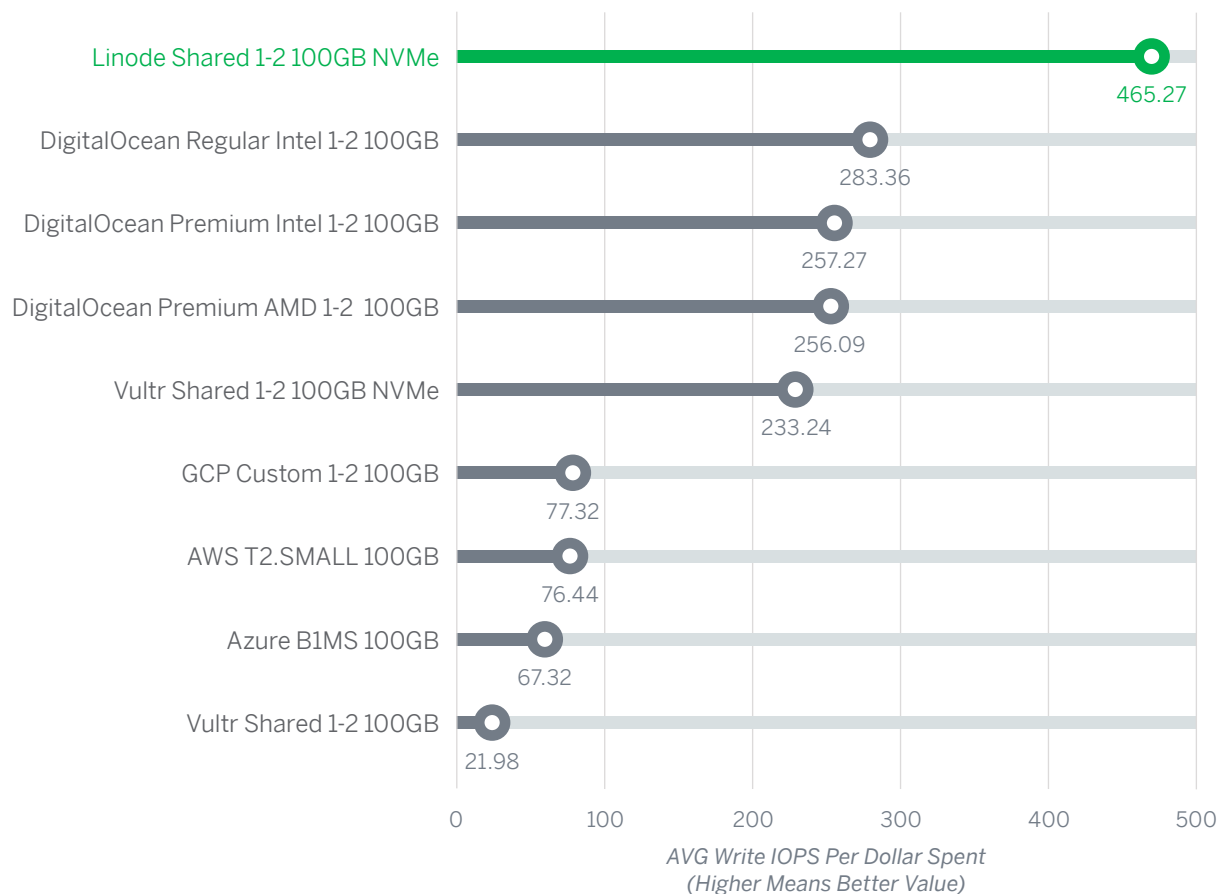
\$ Shared VMs (1 CPU) & 500GB Block Storage - 4K Storage Write READ IOPS Per Dollar



1-CPU Shared > Block Storage IOPS Analysis > Price-Performance > Write

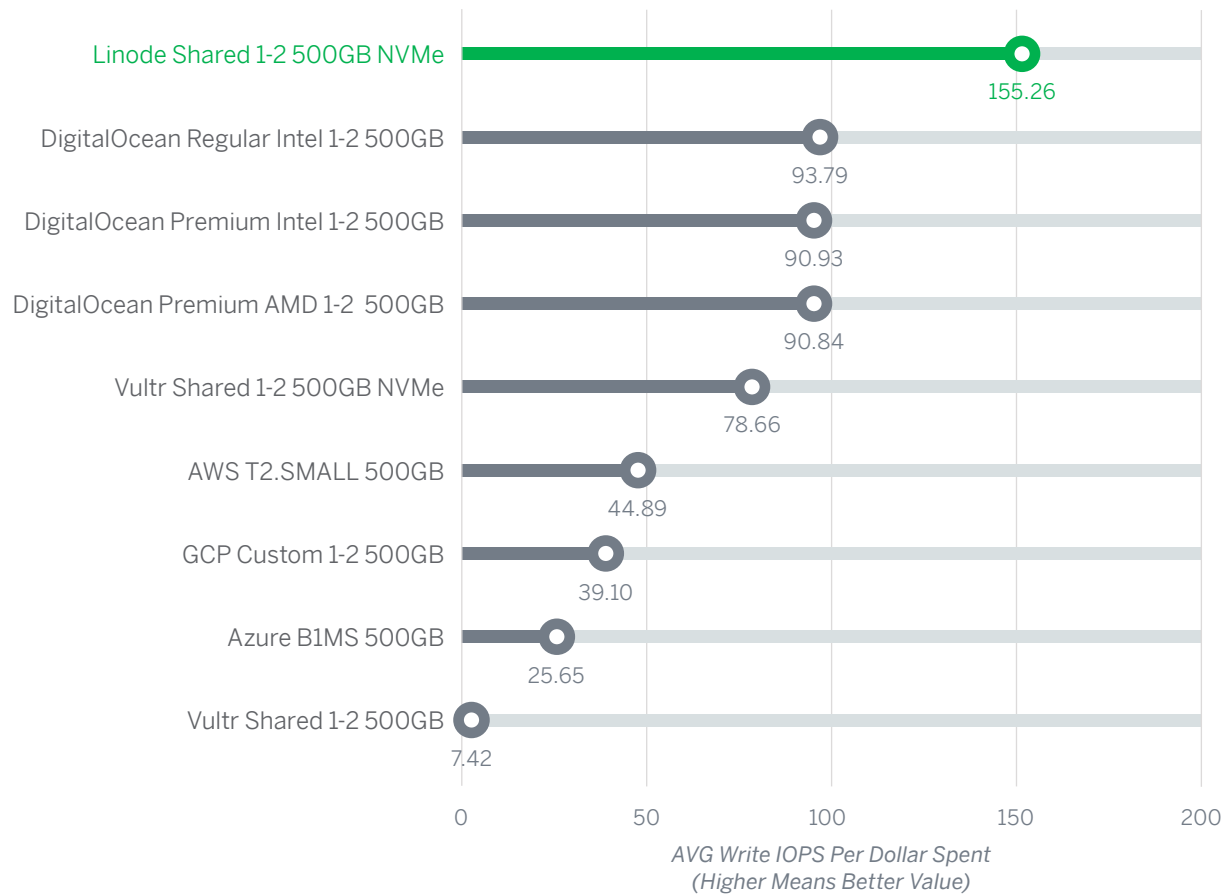
Linode offers the best random write value compared to all other providers with its 100GB NVMe Block Storage volume for Write IOPs per dollar spent, and significantly beats the next closest option by more than 64%. The three large, well-known cloud providers trail behind when it comes to storage value.

\$ Shared VMs (1 CPU) & 100GB Block Storage - 4K Storage Write IOPS Per Dollar



1-CPU Shared > Block Storage IOPS Analysis > Price-Performance > Write

\$ Shared VMs (1 CPU) & 500GB Block Storage - 4K Storage Write IOPS Per Dollar



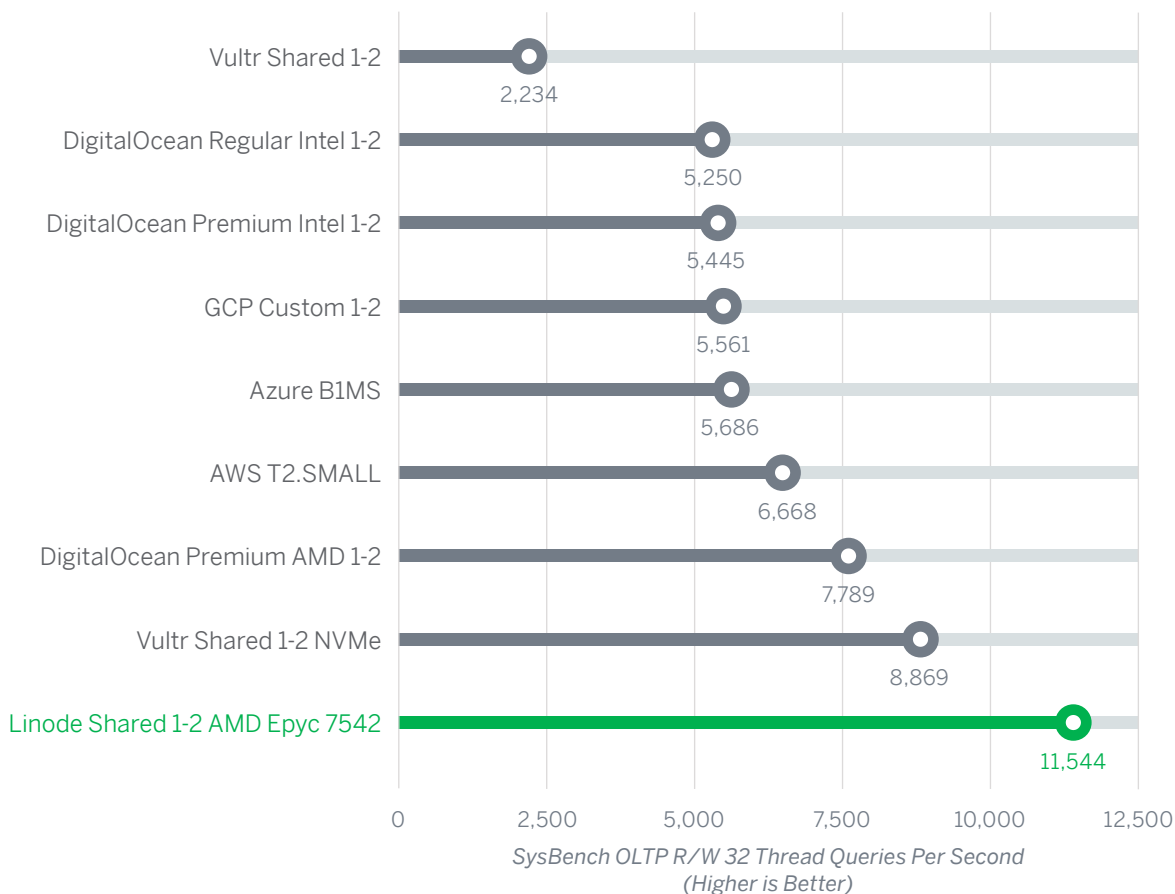
1-CPU Shared > Database Performance > OLTP Queries Per Second

Database Performance

Linode continues to lead when it comes to database performance with the highest queries per second compared to all other 1-CPU VMs. Linode offers the best CPU and storage performance in this class of VMs, beating the next closest provider, Vultr, by more than 30%.



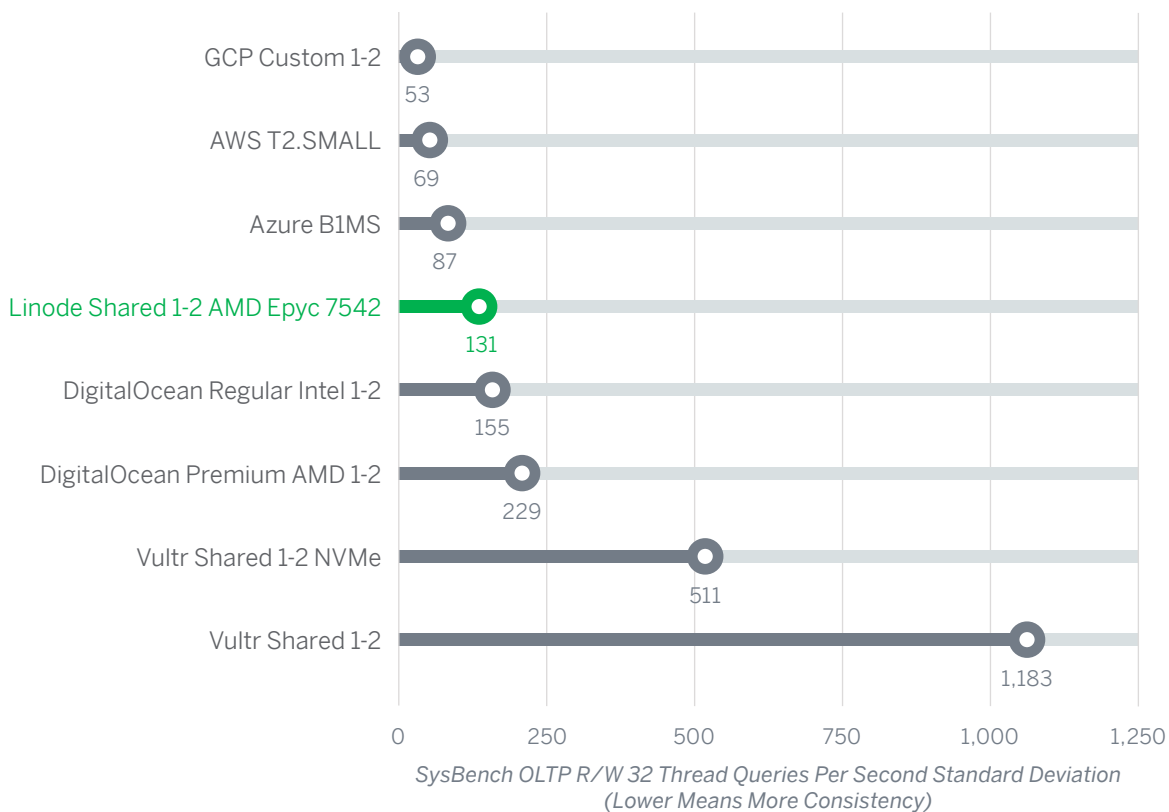
Shared VMs (1 CPU) - OLTP Average Queries Per Second



1-CPU Shared > Database Performance > OLTP Queries Per Second

Looking at database performance consistency, the three large, well-known providers offer the most consistent database performance compared to the other vendors..

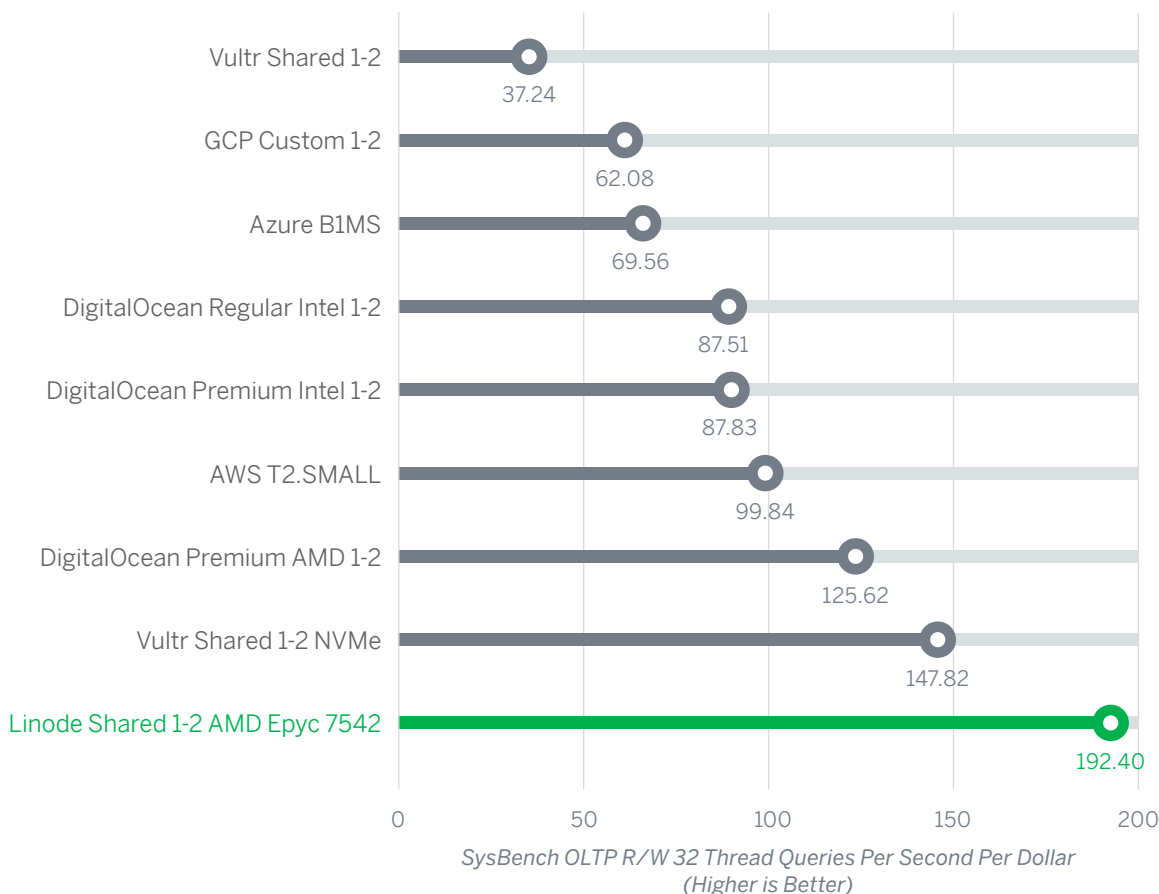
★ Shared VMs (1 CPU) - OLTP Queries Per Second Std Dev



1-CPU Shared > Database Performance > OLTP Queries Price-Performance

Looking at database performance per dollar spent, Linode's shared plan offers the most queries per dollar spent due to its extremely low cost.

\$ Shared VMs (1 CPU) - OLTP Queries Per Second Per Dollar



Conclusion

NVMe-based block storage provided the best price-performance ratio across a wide range of infrastructure providers when compared to traditional SSD-based block storage. Some of the smaller, alternative providers delivered nearly double the performance per dollar compared to the larger, well-known clouds, with Linode and DigitalOcean delivering 200% better database performance per dollar spent than AWS, Azure, and GCP. Amazon and Microsoft block storage offerings consistently underperformed all others in this benchmark cohort.

About Linode

[Linode](#) accelerates innovation by making cloud computing simple, accessible, and affordable to all. Linode is part of a select group of hyperscale cloud infrastructure providers giving individual developers, small business owners and enterprise innovation teams an alternative to the costly, complex, and competitive choices they currently have in the market. Founded in 2003, Linode helped pioneer the cloud computing industry and is today the largest independent cloud provider in the world. More than a million developers and businesses across 196 countries served by a global network of 11 data centers trust Linode with their cloud computing business.

About Cloud Spectator

Cloud Spectator is a cloud benchmarking and consulting firm focused on the performance of IaaS and applications in the Cloud.

Cloud Spectator provides a full spectrum of cloud consulting services, including strategy and planning, architecture and technology selection, deployment, and implementation, as well as Cloud migration services. Cloud Spectator also helps cloud providers understand their market position and helps businesses make intelligent decisions related to cloud strategy, cloud readiness, cost reduction, and vendor analysis.

Appendix

In addition to this report's comprehensive block storage performance assessment, the following appendices provide more general CPU performance based on 1-CPU and 4-CPU VM sizes.

The block storage performance analysis in the primary benchmark report is broken down into two groups based on the VMs' CPU counts. All VMs have the same amount of RAM in each group along with matching block storage volume sizes. The Linode plans used in this test have the latest generation of AMD 7542 processors.

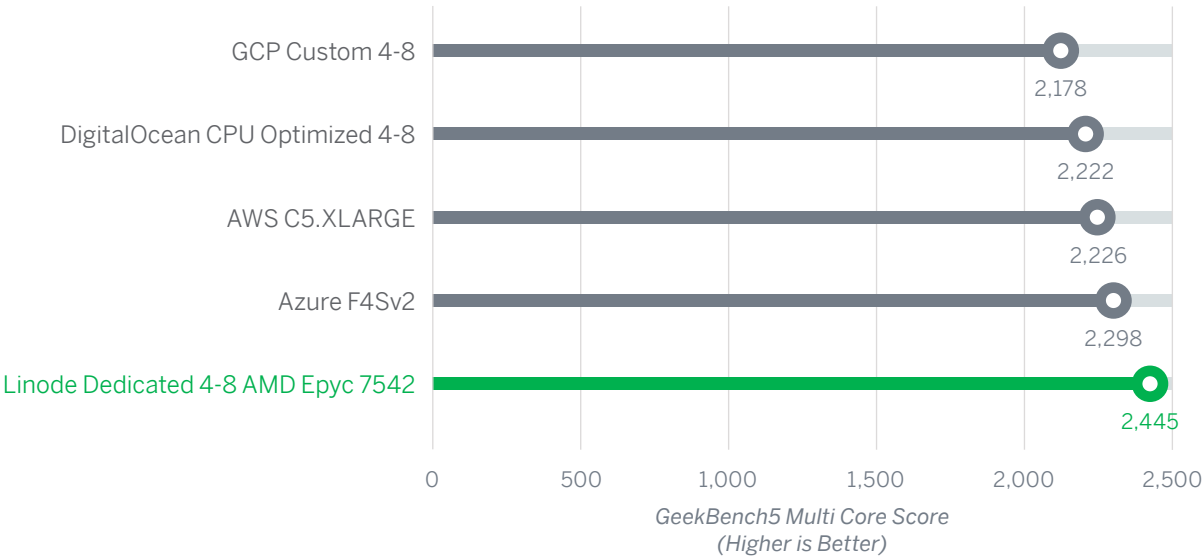
Testing two different VM types (shared vs. dedicated) and sizes allows us to determine if block storage performance scales with CPU counts and/or exclusive access to CPU resources by testing the 500GB volume in both groups. Additionally, this selection allows us to see which providers scale block storage performance based on the size provisioned. Each provider's most readily available block storage offering was included in all of these tests, with the exception of Vultr. To ensure benchmarks were as fair as possible, Cloud Spectator tested both first generation block storage and NVMe block storage from Vultr, which was in beta at the time of this report.

Appendix

4-CPU Dedicated VM CPU Performance

For the dedicated CPU performance, the results are pretty close, but Linode takes the top spot.

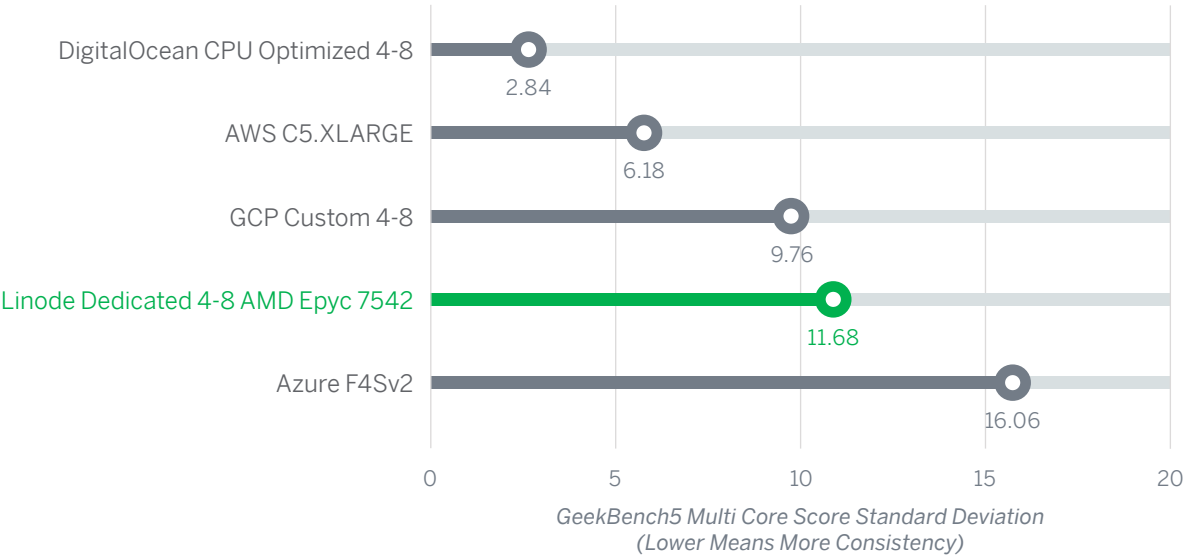
★ 4-CPU Dedicated VMs - CPU Performance



Appendix

Measuring CPU performance consistency shows that DigitalOcean had the most consistent results. Linode came fourth in this case, but is still much closer to the top three than Azure.

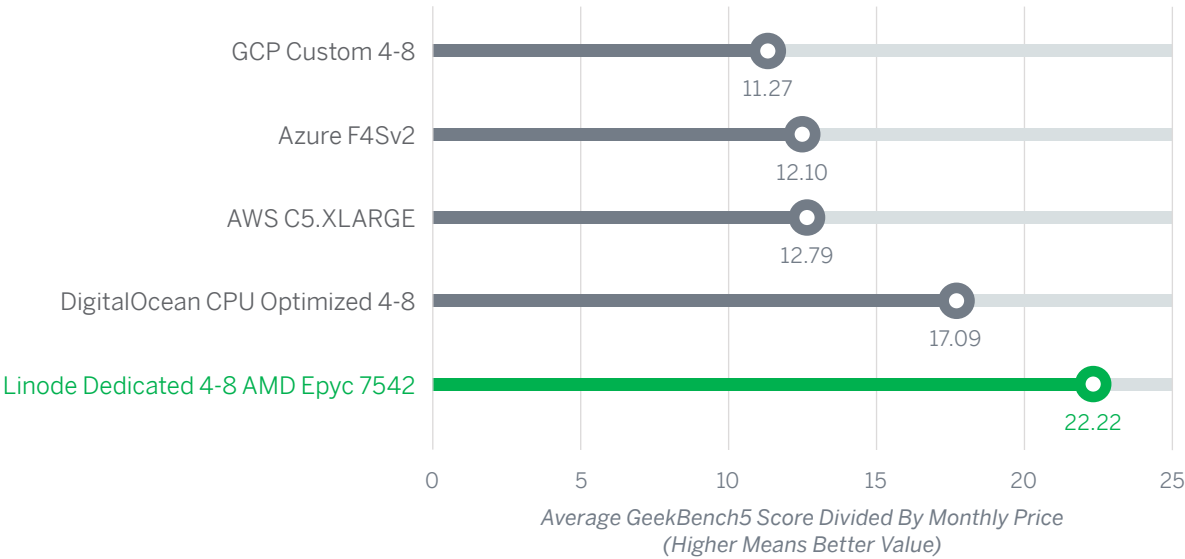
★ 4-CPU Dedicated VMs - CPU Performance Std Dev



Appendix

When looking at the CPU performance per dollar spent in the 4-CPU VM group, **Linode continues to lead the pack by a substantial margin** with DigitalOcean coming in second place. The three hyperscale providers show very similar results with close to double the cost in terms of CPU performance per dollar compared to Linode. (Performance Per Dollar uses the price of the smallest block storage drive.)

 **4-CPU Dedicated VMs - CPU Performance Per Dollar**



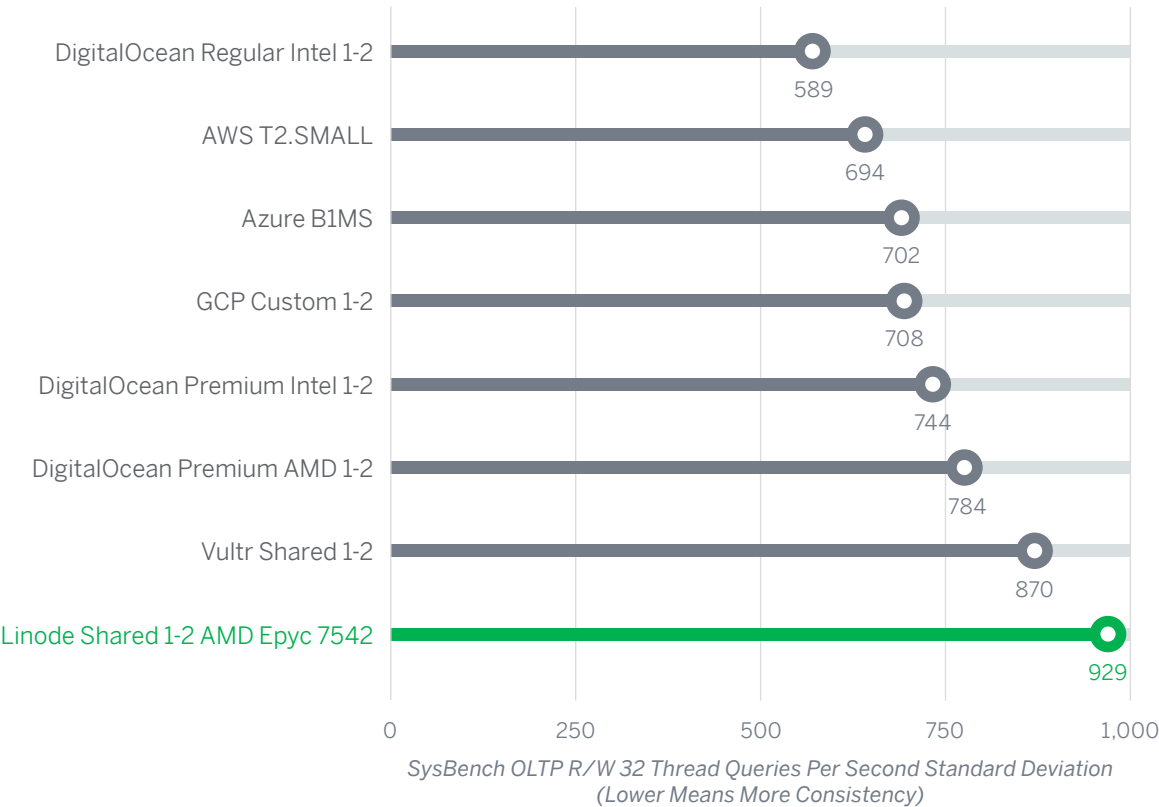
Appendix

1-CPU Shared VM Performance

The results in the section below are focused on the 1-CPU VMs with 100GB and 500GB block storage volumes.

Linode's 1-CPU 2GB RAM VM takes the top spot when it comes to GeekBench5 multi-core CPU performance, **beating the next closest competitor (Vultr) by 7%**. Linode's shared 2GB VM is using one of the latest AMD EPYC CPUs, which offers incredible performance compared to both older AMD models and Intel CPUs used by DigitalOcean's premium shared plans.

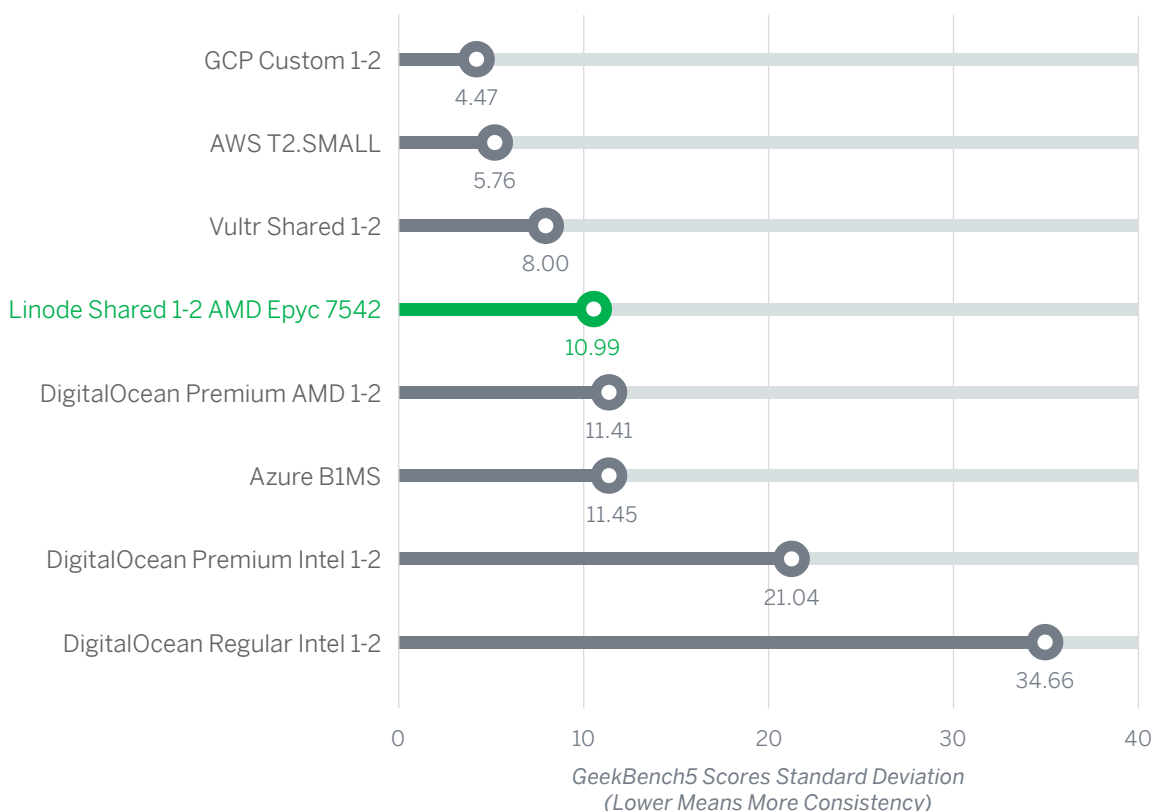
★ 1-CPU Shared VMs - CPU Performance



Appendix

Looking at performance consistency, GCP takes the top spot, followed by AWS and Vultr. Linode falls in the middle of the pack, but interestingly, DigitalOcean falls far behind with both their Regular and Premium Intel processors. Their Premium AMD plan is significantly more competitive in terms of performance consistency compared to other providers.

★ 1-CPU VMs - CPU Performance



Appendix

Again, Linode takes the top spot for CPU performance per dollar spent for the 1-CPU group, providing triple the CPU performance value of GCP.

\$ 1-CPU Shared VMs - CPU Performance Per Dollar

