

# Comparing the Cost of Cloud Services Provided by AWS and Azure

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# Background



# What is Cloud Computing?

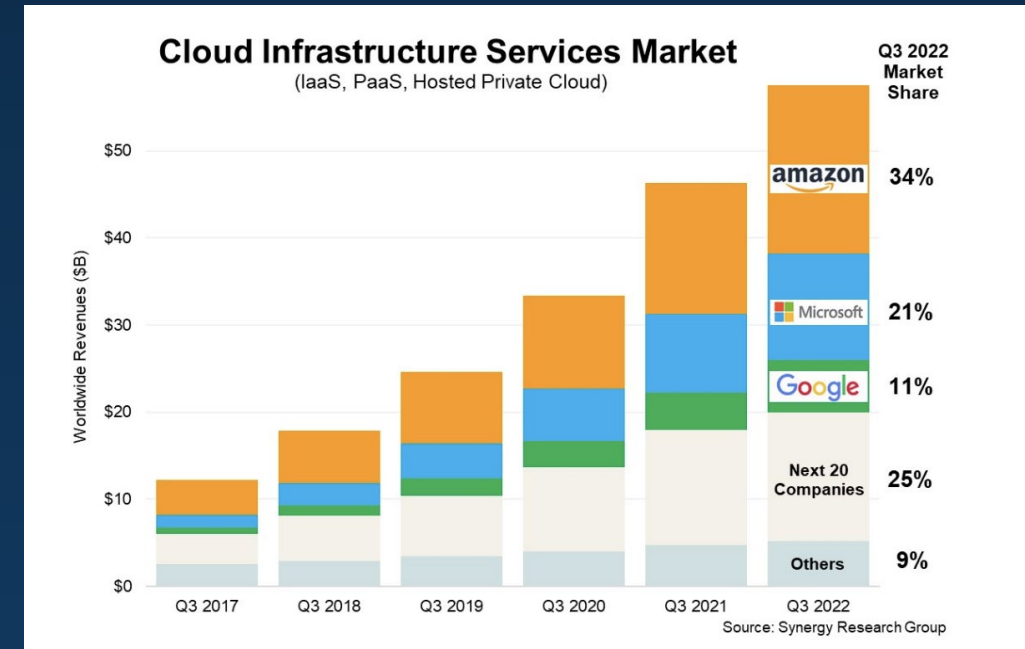
- Cloud Computing is the practice of using networked remote servers hosted on the internet to store, manage, process, and deliver data
- Cloud Service Providers (CSPs) have invested heavily into large optimized data centers stacked with computational resources that can be shared with customers
- Data centers allow customers to shift focus away from development and maintenance of infrastructure by accessing a readily available and scalable solution for a fee
- CSPs define all rules for purchasing a portion of the computational infrastructure with defined rates based on region, performance characteristics, and utilization time

# Why Amazon Web Services vs Microsoft Azure?

- AWS and Azure currently hold more than half of the total market share for Cloud Infrastructure Services (34% and 21% respectively)
  - Does not consider investment/profit, only annual revenue
  - Similar flexibility and options (IaaS, PaaS, SaaS, and Private Cloud)
  - Multiple global regions offered
  - Government Cloud offerings



- AWS and Azure offer comprehensive pricing calculators for Virtual Machine computing
  - Similar specification selection: CPU cores, memory, instance storage, GPU
  - Allows for customers to perform quick estimation without tediously requesting individual quotations
  - Results available as dollars/hour of usage



Market Share Image Source: WIRE19 Utilizing Data from Synergy Research Group

# Analysis Objectives and Scope

## • Objective

- Identify and quantify any cost variances for analogous cloud offerings present within the AWS and Azure pricing calculators

## • Scope

- Infrastructure as a Service (IaaS) cloud environment
- Calculator pricing for all Instances / Virtual Machines (VMs) in common region for cloud services with various Operating Systems
- Data validated to be accurate in both CSPs pricing calculators on February 20, 2023

# Data Collection



## Data Collection Preliminaries

- Selected United States East as common region (US East Region for AWS and East US Region for Azure) for public cloud hosting
- Pricing data is for on-demand capacity with pay-as-you-go billing, no discount rates considered (reserved instances or forward financed)
- Comparison of publicly listed CSP pricing calculator rates for AWS and Azure, not actual usage data
- Cloud Services beyond usage of instances/VMs are not considered
- Underlying data center hardware was not considered, only technical specifications of instances/VMs stated in pricing calculator





# Azure Virtual Machine Data

- Azure VM data compiled directly from the Azure Pricing Calculator
- Pricing data for 442 VM types recorded for Commercial (East US) and US Gov (Virginia)
- Identified 6 VM categories with the following counts:
  - General Purpose – 105 VMs
  - Compute Optimized (CO) – 23 VMs
  - Memory Optimized – 235 VMs
  - Storage Optimized – 10 VMs
  - GPU Instances – 39 VMs
  - Other – 30 VMs
- Compiled 2,655 hourly rate data points for Azure VMs

## Azure VM Pricing Calculator

| VM Series | Category          | vCPUs | Memory (GB) | Instance Storage (GB) | Commercial - On-Demand Instances East US (\$/Hr) |               |                                |                                   | On-Demand Instances US Gov Virginia (\$/Hr) |               |                                |                                   |
|-----------|-------------------|-------|-------------|-----------------------|--|---------------|--------------------------------|-----------------------------------|---|---------------|--------------------------------|-----------------------------------|
|           |                   |       |             |                       | Linux Usage                                      | Windows Usage | Red Hat Enterprise Linux Usage | Windows with SQL Enterprise Usage | Linux Usage                                 | Windows Usage | Red Hat Enterprise Linux Usage | Windows with SQL Enterprise Usage |
| F4        | Compute Optimized | 4     | 8           | 64                    | \$0.199  | \$0.383       | \$0.259                        | \$1.883                           | \$0.239                                     | \$0.423       | \$0.299                        | \$1.923                           |

Compiled Azure VM Pricing Workbook – Example

# AWS Instance Data

- AWS Instance data compiled directly from the AWS EC2 Pricing Calculator
- Pricing data for 309 instance types recorded for Commercial (US East) and GovCloud (US East)
- Identified 6 instance categories with the following counts:
  - General Purpose – 103 Instances
  - Compute Optimized (CO) – 56 Instances
  - Memory Optimized – 92 Instances
  - Storage Optimized – 28 Instances
  - GPU Instances – 19 instances
  - Other – 11 Instances
- Compiled 2,143 hourly rate data points for AWS Instances

## AWS EC2 On-Demand Pricing Calculator

On-Demand Plans for Amazon EC2

Select a location type and region

Location Type: AWS Region | Region: US East (Ohio)

Select an operating system, instance type, and vCPU to view rates

Operating system: Linux

Instance type: All | vCPU: All

Viewing 489 of 489 available instances

Search: c5.x

| Instance name | On-Demand hourly rate | vCPU | Memory | Storage  | Network performance |
|---------------|-----------------------|------|--------|----------|---------------------|
| c5.xlarge     | \$0.17                | 4    | 8 GiB  | EBS Only | Up to 10 Gigabit    |

| Instance Type | Category          | vCPU | Memory (GiB) | Instance Storage (GB) | Commercial - On-Demand Instances East US (\$/Hr) |               |                                |                                   | On-Demand Instances US Gov Virginia (\$/Hr) |               |                                |                                   |
|---------------|-------------------|------|--------------|-----------------------|--|---------------|--------------------------------|-----------------------------------|---|---------------|--------------------------------|-----------------------------------|
|               |                   |      |              |                       | Linux Usage                                      | Windows Usage | Red Hat Enterprise Linux Usage | Windows with SQL Enterprise Usage | Linux Usage                                 | Windows Usage | Red Hat Enterprise Linux Usage | Windows with SQL Enterprise Usage |
| c5.xlarge     | Compute Optimized | 4    | 8            | EBS Only              | \$0.170  | \$0.354       | \$0.230                        | \$1.854                           | \$0.204                                     | \$0.264       | \$0.388                        | \$0.868                           |

Compiled AWS Instance Pricing Workbook - Example

# AWS EBS Pricing

- Most AWS instances utilize Elastic Block Storage (EBS) for instance storage, a variable storage volume that can be mounted to the instance
  - EBS costs are independent from instance costs
  - AWS instances can utilize less EBS when it is not needed
    - Azure doesn't offer this flexibility for temporary storage
- EBS pricing was determined utilizing Amazon EBS Calculator
  - General Purpose SSD (gp2) has been utilized
  - 30 different EBS storage and duration combinations were entered to determine the representative hourly cost per GB of \$0.000137 (\$0.10/730 hours) for Commercial and \$0.000165 (\$0.12/730 hours) for GovCloud
- AWS instances utilizing EBS storage have been evaluated using the instance memory value associated with an analogous Azure VM to increase the sample size of comparisons

| Commercial EBS |                        |
|----------------|------------------------|
| Statistics     | EBS Hourly Cost Per GB |
| Average:       | \$ 0.0001373           |
| Min            | \$ 0.0001350           |
| Max            | \$ 0.0001400           |
| Range          | \$ 0.0000050           |
| Std Dev        | \$ 0.0000016           |

| GovCloud EBS |                        |
|--------------|------------------------|
| Statistics   | EBS Hourly Cost Per GB |
| Average:     | \$ 0.00016478          |
| Min          | \$ 0.00016191          |
| Max          | \$ 0.00016801          |
| Range        | \$ 0.00000609          |
| Std Dev      | \$ 0.00000190          |

## AWS EBS Pricing Calculator

Configure Amazon Elastic Block Store (EBS) [Info](#)

Select location type [Info](#) Select region

Region

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**Service Settings** [Info](#)

**Calculating EBS snapshots**  
[Learn more on how EBS snapshot prices are calculated.](#)

Number of volumes

Average duration each instance runs  hours per month

Storage for each EC2 instance  
 Choose EBS volume storage type.

**Volume type selected supports storage amounts 1 GB - 16 TB**

Storage amount per volume  GB

Snapshot Frequency

Total Upfront cost: 0.00 USD [Show Details](#) Save and  
 Total Monthly cost: 0.10 USD

# EBS Analysis – AWS EBS vs Dedicated instances

| Resources                |       |              |                       |                    |       |              |                       | Commercial Services [EBS/Fixed] |             |             |             | Government Services [EBS/Fixed] |             |             |             |
|--------------------------|-------|--------------|-----------------------|--------------------|-------|--------------|-----------------------|---------------------------------|-------------|-------------|-------------|---------------------------------|-------------|-------------|-------------|
| AWS w/ Fixed Storage     |       |              |                       | AWS w/ EBS Only    |       |              |                       | Linux                           | Windows     | Red Hat     | SQL Ent.    | Linux                           | Windows     | Red Hat     | SQL Ent.    |
| AWS Instance (Dedicated) | vCPUs | Memory (GiB) | Instance Storage (GB) | AWS Instance (EBS) | vCPUs | Memory (GiB) | Instance Storage (GB) | % EBS/Fixed                     | % EBS/Fixed | % EBS/Fixed | % EBS/Fixed | % EBS/Fixed                     | % EBS/Fixed | % EBS/Fixed | % EBS/Fixed |
| m5d.8xlarge              | 32    | 128          | 1200                  | m5.8xlarge         | 32    | 128          | EBS Only              | 94.07%                          | 96.73%      | 94.47%      | 99.30%      | 93.26%                          | 95.90%      | 93.62%      | 99.02%      |
| m5d.xlarge               | 4     | 16           | 150                   | m5.xlarge          | 4     | 16           | EBS Only              | 94.07%                          | 96.73%      | 95.31%      | 99.30%      | 93.26%                          | 95.90%      | 94.43%      | 99.02%      |
| m5d.2xlarge              | 8     | 32           | 300                   | m5.2xlarge         | 8     | 32           | EBS Only              | 94.07%                          | 96.73%      | 95.39%      | 99.30%      | 93.26%                          | 95.90%      | 94.51%      | 99.02%      |
| m5d.4xlarge              | 16    | 64           | 600                   | m5.4xlarge         | 16    | 64           | EBS Only              | 94.07%                          | 96.73%      | 94.81%      | 99.30%      | 93.26%                          | 95.90%      | 93.95%      | 99.02%      |
| m5d.12xlarge             | 48    | 192          | 1800                  | m5.12xlarge        | 48    | 192          | EBS Only              | 94.07%                          | 96.73%      | 94.34%      | 99.30%      | 93.26%                          | 95.90%      | 93.50%      | 99.02%      |
| m5d.16xlarge             | 64    | 256          | 2400                  | m5.16xlarge        | 64    | 256          | EBS Only              | 94.07%                          | 96.73%      | 94.27%      | 99.30%      | 93.26%                          | 95.90%      | 93.44%      | 99.02%      |
| r5d.2xlarge              | 8     | 64           | 300                   | r5.2xlarge         | 8     | 64           | EBS Only              | 94.65%                          | 96.74%      | 95.64%      | 99.22%      | 94.43%                          | 96.36%      | 95.31%      | 99.05%      |
| r5d.8xlarge              | 32    | 256          | 1200                  | r5.8xlarge         | 32    | 256          | EBS Only              | 94.65%                          | 96.74%      | 94.94%      | 99.22%      | 94.43%                          | 96.36%      | 94.68%      | 99.05%      |
| r5d.12xlarge             | 48    | 384          | 1800                  | r5.12xlarge        | 48    | 384          | EBS Only              | 94.65%                          | 96.74%      | 94.85%      | 99.22%      | 94.43%                          | 96.36%      | 94.60%      | 99.05%      |

- Comparing AWS Instances with dedicated instance storage against analogous instances without dedicated instances storage shows that dedicated instances storage is more expensive. This is in part because they are supported by NVMe SSD rather than general purpose SSD
- The technical specifications for the dedicated temporary storage for Azure VMs couldn't be identified, so nothing has been done to account for this within the analysis

# Analysis and Results



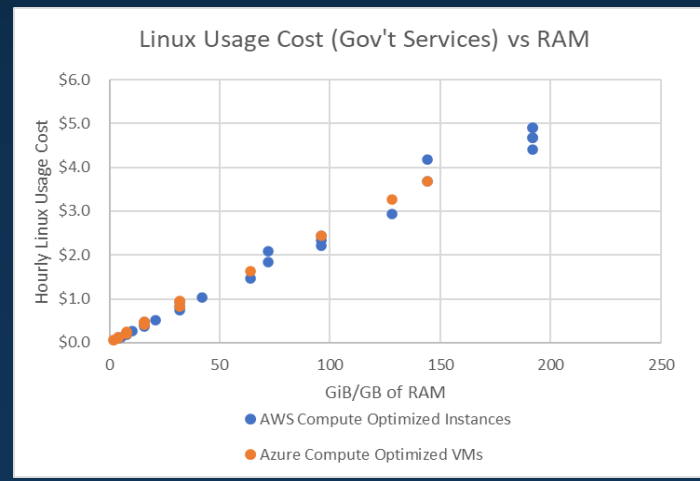
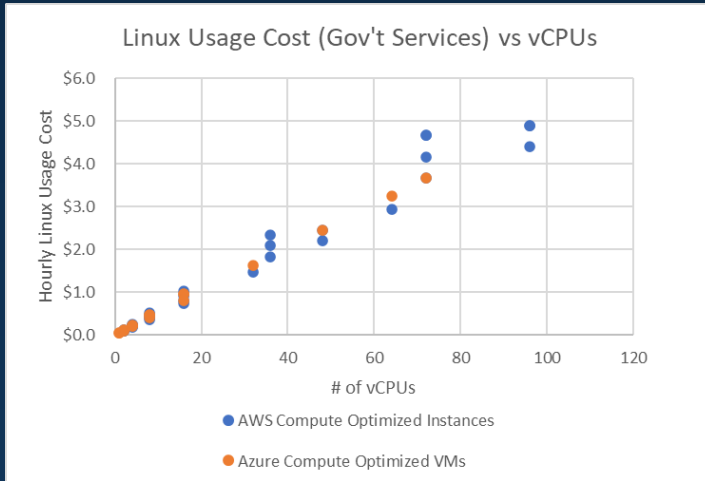
# Analysis Plan

1. Investigate relationships between technical parameters and usage cost
2. Identify instance/VM pairs with identical technical parameters in the CSP provided calculators
3. Compare the cost of each instance/VM pair between the two CSPs for each usage case
4. Utilize each of the comparisons to determine a weighted average that represents the relative cost for instance/VMs of a specific performance category for a specific usage case

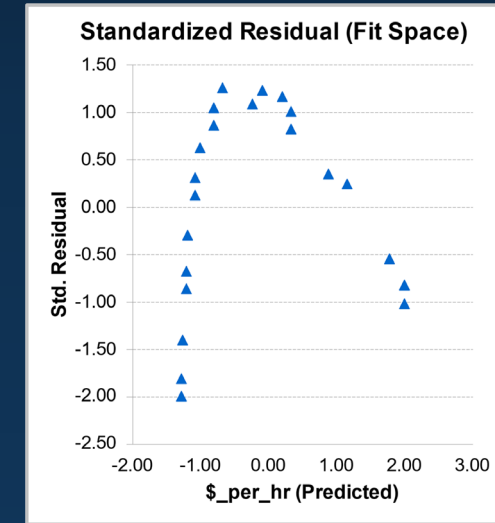
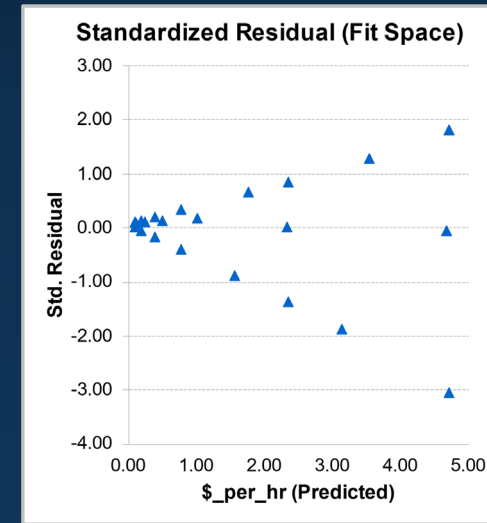


# Resource Utilization Cost Trends – Compute Optimized

## (vCPU/RAM) vs Usage for Compute Optimized AWS Instances / Azure VMs (Linux Usage)



## Residuals from Multivariate Regression on AWS Compute Optimized Instances (Linux Usage)



- Usage cost for instances/VMs demonstrate a strong linear relation to vCPU quantities or RAM sizing
- Multivariate regression exhibits undesirable patterns within standardized residual plot
- To make a fair comparison between the CSPs the analysis will focus on investigating a subset of AWS Instances and Azure VMs with identical specifications

# Identifying Reasonable Comparisons – Compute Optimized

| vCPU Values | AWS Instance Count | Azure VM Count | Potential Comparisons |
|-------------|--------------------|----------------|-----------------------|
| 1           | 2                  | 2              | 4                     |
| 2           | 7                  | 3              | 21                    |
| 4           | 7                  | 4              | 28                    |
| 8           | 7                  | 3              | 21                    |
| 16          | 7                  | 3              | 21                    |
| 32          | 3                  | 1              | 3                     |
| 36          | 4                  | 0              | 0                     |
| 48          | 5                  | 1              | 5                     |
| 64          | 5                  | 1              | 5                     |
| 72          | 4                  | 1              | 4                     |
| Summary     | 51                 | 19             | 112                   |

Potential Comparisons Based on vCPU

| RAM Values (GiB/GB) | AWS Instance Count | Azure Count | Potential Comparisons |
|---------------------|--------------------|-------------|-----------------------|
| 2                   | 2                  | 2           | 4                     |
| 4                   | 5                  | 3           | 15                    |
| 8                   | 5                  | 3           | 15                    |
| 16                  | 5                  | 3           | 15                    |
| 32                  | 5                  | 3           | 15                    |
| 64                  | 3                  | 1           | 3                     |
| 96                  | 6                  | 1           | 6                     |
| 128                 | 5                  | 1           | 5                     |
| 144                 | 2                  | 1           | 2                     |
| Summary             | 38                 | 18          | 80                    |

Potential Comparisons Based on RAM

- Tables represent instances/VMs from both CSPs with analogous vCPU/RAM values
- Restricting analysis to identical specifications significantly reduces available data points
  - Provides a reasonable comparison utilizing only parameters provided within CSP pricing calculators
- Fun Fact: AWS reports instance RAM as GiB (gibibyte) while Azure uses GB (gigabyte) within pricing calculator
  - 1 GiB is comprised of 1,073,741,824 bytes while mathematically 1 GB is 1,000,000,000 bytes
  - Difference not considered in analysis, assumed Azure uses simplified designation of RAM easily understood by consumers familiar with 1,2,4,8,16,...GB RAM module sizes



# Summary of Valid Comparisons

- Identified 38 AWS instances and 46 Azure VMs valid for comparison

- Each pair of instances/VMs with analogous specifications from both AWS and Azure were compared

- Each Instance/VM contributes only one value to the weighted average for the category they are a member of
  - This value is the average of all comparisons the Instance/VM was grouped into

| Comparison Type                       | AWS Instances | Azure VMs | Potential Comparisons |
|---------------------------------------|---------------|-----------|-----------------------|
| All Instances/VMs                     | 56            | 23        | 1288                  |
| Same vCPUs                            | 51            | 19        | 112                   |
| Same RAM                              | 38            | 18        | 80                    |
| Same Instance Storage (Excluding EBS) | 0             | 0         | 0                     |
| Same vCPUs and RAM                    | 11            | 13        | 23                    |

## Compute Optimized Valid Comparisons

| Category                 | AWS Instances | Azure VMs | Comparisons |
|--------------------------|---------------|-----------|-------------|
| Identical Specifications | 10            | 18        | 18          |
| General Purpose          | 9             | 8         | 10          |
| Compute Optimized        | 11            | 13        | 23          |
| Memory Optimized         | 8             | 7         | 10          |
| Storage Optimized        | N/A           | N/A       | N/A         |
| GPU Instances            | N/A           | N/A       | N/A         |

## Instance Categories and Comparisons

# Cost Comparison – Example Calculation

| AWS Instance        |                       |                     |              |                       |  |               |               |                      |  |               |               |                      |
|---------------------|-----------------------|---------------------|--------------|-----------------------|--|---------------|---------------|----------------------|--|---------------|---------------|----------------------|
| Specifications      |                       |                     |              |                       | Commercial - On-Demand Instances (\$/Hr) |               |               |                      | GovCloud - On-Demand Instances (\$/Hr) |               |               |                      |
| Instance Type       | Category              | vCPU                | Memory (GiB) | Instance Storage (GB) | Linux Usage                              | Windows Usage | Red Hat Usage | SQL Enterprise Usage | Linux Usage                            | Windows Usage | Red Hat Usage | SQL Enterprise Usage |
| c5.xlarge           | Compute Optimized     | 4                   | 8            | EBS Only              | \$0.170                                  | \$0.354       | \$0.230       | \$1.854              | \$0.204                                | \$0.388       | \$0.264       | \$1.888              |
| EBS Storage (64 GB) |                       |                     |              |                       | \$0.009                                  | \$0.009       | \$0.009       | \$0.009              | \$0.011                                | \$0.011       | \$0.011       | \$0.011              |
| Total               |                       |                     |              |                       | \$0.179                                  | \$0.363       | \$0.239       | \$1.863              | \$0.215                                | \$0.399       | \$0.275       | \$1.899              |
| EBS Storage inputs  |                       |                     |              |                       |  |               |               |                      |  |               |               |                      |
| Instance GB         | Commercial Cost/GB hr | GovCloud Cost/GB hr |              |                       |  |               |               |                      |  |               |               |                      |
| 64                  | \$0.000137            | \$0.000165          |              |                       |  |               |               |                      |  |               |               |                      |

| Azure VM       |                   |      |             |                       |  |               |               |                      |   |               |               |                      |
|----------------|-------------------|------|-------------|-----------------------|--|---------------|---------------|----------------------|---|---------------|---------------|----------------------|
| Specifications |                   |      |             |                       | Commercial - On-Demand Instances East US (\$/Hr) |               |               |                      | On-Demand Instances US Gov Virginia (\$/Hr) |               |               |                      |
| VM Series      | Category          | vCPU | Memory (GB) | Instance Storage (GB) | Linux Usage                                      | Windows Usage | Red Hat Usage | SQL Enterprise Usage | Linux Usage                                 | Windows Usage | Red Hat Usage | SQL Enterprise Usage |
| F4             | Compute Optimized | 4    | 8           | 64                    | \$0.199  | \$0.383       | \$0.259       | \$1.883              | \$0.239                                     | \$0.423       | \$0.299       | \$1.923              |

## VM Cost Comparison – AWS c5.xlarge vs Azure F4

| AWS vs Azure VM Comparison |             |               |               |                      |             |               |               |                      |
|----------------------------|-------------|---------------|---------------|----------------------|-------------|---------------|---------------|----------------------|
| Comparison                 | Linux Usage | Windows Usage | Red Hat Usage | SQL Enterprise Usage | Linux Usage | Windows Usage | Red Hat Usage | SQL Enterprise Usage |
| AWS - Azure Total \$/hr    | (\$0.020)   | (\$0.020)     | (\$0.020)     | (\$0.020)            | (\$0.024)   | (\$0.024)     | (\$0.024)     | (\$0.024)            |
| Azure / AWS %              | 111%        | 106%          | 108%          | 101%                 | 111%        | 106%          | 109%          | 101%                 |

# Computing the Weighted Average – Gov't Linux: Compute Optimized

|                               | Gov't Services %<br>Azure/AWS (Linux) | AWS<br>Instance | AWS Instance<br>Weighted % | Azure VM | Azure Instance<br>Weighted % |
|-------------------------------|---------------------------------------|-----------------|----------------------------|----------|------------------------------|
| Compute<br>Optimized<br>(EBS) | 111.40%                               | c5.xlarge       | 108.18%                    | F4       | 117.12%                      |
|                               | 115.66%                               | c5.xlarge       |                            | F4s      | 121.86%                      |
|                               | 97.48%                                | c5.xlarge       |                            | F4s v2   | 102.63%                      |
|                               | 122.85%                               | c5a.xlarge      | 119.56%                    | F4       |                              |
|                               | 128.06%                               | c5a.xlarge      |                            | F4s      |                              |
|                               | 107.78%                               | c5a.xlarge      |                            | F4s v2   |                              |
|                               | 111.63%                               | c5.2xlarge      | 108.34%                    | F8       | 117.37%                      |
|                               | 115.90%                               | c5.2xlarge      |                            | F8s      | 122.11%                      |
|                               | 97.48%                                | c5.2xlarge      |                            | F8s v2   | 102.63%                      |
|                               | 123.11%                               | c5a.2xlarge     | 119.74%                    | F8       |                              |
|                               | 128.32%                               | c5a.2xlarge     |                            | F8s      |                              |
|                               | 107.78%                               | c5a.2xlarge     |                            | F8s v2   |                              |
|                               | 111.51%                               | c5.4xlarge      | 108.26%                    | F16      | 117.25%                      |
|                               | 115.78%                               | c5.4xlarge      |                            | F16s     | 121.99%                      |
|                               | 97.48%                                | c5.4xlarge      |                            | F16s v2  | 102.63%                      |
|                               | 122.98%                               | c5a.4xlarge     | 119.65%                    | F16      |                              |
|                               | 128.19%                               | c5a.4xlarge     |                            | F16s     |                              |
|                               | 107.78%                               | c5a.4xlarge     |                            | F16s v2  |                              |
|                               | 107.78%                               | c5a.8xlarge     | 107.78%                    | F32s v2  | 107.78%                      |
|                               | 97.48%                                | c5.12xlarge     | 97.48%                     | F48s v2  | 102.63%                      |
| 107.78%                       | c5a.12xlarge                          | 107.78%         | F48s v2                    |          |                              |
| 107.78%                       | c5a.16xlarge                          | 107.78%         | F64s v2                    | 107.78%  |                              |
| 97.48%                        | c5.18xlarge                           | 97.48%          | F72s v2                    | 97.48%   |                              |
| <b>Average</b>                | <b>111.72%</b>                        |                 | <b>109.28%</b>             |          | <b>110.87%</b>               |
|                               | <b>Weighted Average</b>               |                 | <b>110.07%</b>             |          |                              |

- Because the comparisons are based on indistinguishable parameters, each set of identical instances/VMs are compared
- The relative cost for each of the comparisons that an instance/VM participates in are averaged to establish the value that VM contributes to the category average
- This category average is computed for each CSP, and these two values are then averaged to determine the weighted average for each usage case.

# Compute Optimized Comparisons

|                         | Resources    |          |       |                 |                       | Commercial Services (Delta \$/Hr) \$[AWS - Azure], [Azure/AWS]% |             |             |             |                          |             |                             |             | Government Services (Delta \$/hr) [AWS - Azure]\$, [Azure/AWS]% |             |             |             |                          |             |                             |             |
|-------------------------|--------------|----------|-------|-----------------|-----------------------|---|-------------|-------------|-------------|--------------------------|-------------|-----------------------------|-------------|---|-------------|-------------|-------------|--------------------------|-------------|-----------------------------|-------------|
|                         |              |          |       |                 |                       | Linux   |             | Windows     |             | Red Hat Enterprise Linux |             | Windows with SQL Enterprise |             | Linux   |             | Windows     |             | Red Hat Enterprise Linux |             | Windows with SQL Enterprise |             |
|                         | AWS Instance | Azure VM | vCPUs | Memory (GiB/GB) | Instance Storage (GB) | Delta \$/Hr   | % Azure/AWS | Delta \$/Hr | % Azure/AWS | Delta \$/Hr              | % Azure/AWS | Delta \$/Hr                 | % Azure/AWS | Delta \$/Hr   | % Azure/AWS | Delta \$/Hr | % Azure/AWS | Delta \$/Hr              | % Azure/AWS | Delta \$/Hr                 | % Azure/AWS |
| Compute Optimized (EBS) | c5.xlarge    | F4       | 4     | 8               | 64                    | (\$0.02)  | 111%        | (\$0.02)    | 106%        | (\$0.02)                 | 108%        | (\$0.02)                    | 101%        | (\$0.02)  | 111%        | (\$0.02)    | 106%        | (\$0.02)                 | 109%        | (\$0.02)                    | 101%        |
|                         | c5.xlarge    | F4s      | 4     | 8               | 16                    | (\$0.03)  | 116%        | (\$0.03)    | 108%        | (\$0.03)                 | 112%        | (\$0.03)                    | 101%        | (\$0.03)  | 116%        | (\$0.03)    | 108%        | (\$0.03)                 | 112%        | (\$0.03)                    | 102%        |
|                         | c5.xlarge    | F4s v2   | 4     | 8               | 32                    | \$0.01  | 97%         | \$0.03      | 91%         | \$0.01                   | 98%         | \$0.03                      | 98%         | \$0.01  | 97%         | \$0.01      | 99%         | \$0.01                   | 98%         | \$0.01                      | 100%        |
|                         | c5a.xlarge   | F4       | 4     | 8               | 64                    | (\$0.04)  | 122%        | (\$0.04)    | 110%        | (\$0.04)                 | 116%        | (\$0.04)                    | 102%        | (\$0.04)  | 123%        | (\$0.04)    | 112%        | (\$0.04)                 | 117%        | (\$0.04)                    | 102%        |
|                         | c5a.xlarge   | F4s      | 4     | 8               | 16                    | (\$0.04)  | 127%        | (\$0.04)    | 113%        | (\$0.04)                 | 120%        | (\$0.04)                    | 102%        | (\$0.05)  | 128%        | (\$0.05)    | 114%        | (\$0.05)                 | 121%        | (\$0.05)                    | 103%        |
|                         | c5a.xlarge   | F4s v2   | 4     | 8               | 32                    | (\$0.01)  | 107%        | \$0.02      | 95%         | (\$0.01)                 | 105%        | \$0.02                      | 99%         | (\$0.01)  | 108%        | (\$0.01)    | 104%        | (\$0.01)                 | 106%        | (\$0.01)                    | 101%        |
|                         | c5.2xlarge   | F8       | 8     | 16              | 128                   | (\$0.04)  | 111%        | (\$0.04)    | 106%        | (\$0.04)                 | 108%        | (\$0.04)                    | 101%        | (\$0.05)  | 112%        | (\$0.05)    | 106%        | (\$0.05)                 | 109%        | (\$0.05)                    | 101%        |
|                         | c5.2xlarge   | F8s      | 8     | 16              | 32                    | (\$0.05)  | 116%        | (\$0.05)    | 108%        | (\$0.05)                 | 111%        | (\$0.05)                    | 101%        | (\$0.07)  | 116%        | (\$0.07)    | 108%        | (\$0.07)                 | 112%        | (\$0.07)                    | 102%        |
|                         | c5.2xlarge   | F8s v2   | 8     | 16              | 64                    | \$0.01  | 97%         | \$0.07      | 91%         | \$0.01                   | 98%         | \$0.07                      | 98%         | \$0.01  | 97%         | \$0.01      | 99%         | \$0.01                   | 98%         | \$0.01                      | 100%        |
|                         | c5a.2xlarge  | F8       | 8     | 16              | 128                   | (\$0.07)  | 122%        | (\$0.07)    | 110%        | (\$0.07)                 | 116%        | (\$0.07)                    | 102%        | (\$0.09)  | 123%        | (\$0.09)    | 112%        | (\$0.09)                 | 117%        | (\$0.09)                    | 102%        |
|                         | c5a.2xlarge  | F8s      | 8     | 16              | 32                    | (\$0.09)  | 127%        | (\$0.09)    | 113%        | (\$0.09)                 | 119%        | (\$0.09)                    | 102%        | (\$0.11)  | 128%        | (\$0.11)    | 114%        | (\$0.11)                 | 121%        | (\$0.11)                    | 103%        |
|                         | c5a.2xlarge  | F8s v2   | 8     | 16              | 64                    | (\$0.02)  | 107%        | \$0.03      | 95%         | (\$0.02)                 | 105%        | \$0.03                      | 99%         | (\$0.03)  | 108%        | (\$0.03)    | 104%        | (\$0.03)                 | 106%        | (\$0.03)                    | 101%        |
|                         | c5.4xlarge   | F16      | 16    | 32              | 256                   | (\$0.08)  | 111%        | (\$0.08)    | 106%        | (\$0.08)                 | 110%        | (\$0.08)                    | 101%        | (\$0.10)  | 112%        | (\$0.10)    | 106%        | (\$0.10)                 | 110%        | (\$0.10)                    | 101%        |
|                         | c5.4xlarge   | F16s     | 16    | 32              | 64                    | (\$0.11)  | 116%        | (\$0.11)    | 108%        | (\$0.11)                 | 113%        | (\$0.11)                    | 101%        | (\$0.13)  | 116%        | (\$0.13)    | 108%        | (\$0.13)                 | 114%        | (\$0.13)                    | 102%        |
|                         | c5.4xlarge   | F16s v2  | 16    | 32              | 128                   | \$0.02  | 97%         | \$0.13      | 91%         | \$0.02                   | 98%         | \$0.13                      | 98%         | \$0.02  | 97%         | \$0.02      | 99%         | \$0.02                   | 98%         | \$0.02                      | 100%        |
|                         | c5a.4xlarge  | F16      | 16    | 32              | 256                   | (\$0.14)  | 122%        | (\$0.14)    | 110%        | (\$0.14)                 | 119%        | (\$0.14)                    | 102%        | (\$0.18)  | 123%        | (\$0.18)    | 112%        | (\$0.18)                 | 120%        | (\$0.18)                    | 102%        |
|                         | c5a.4xlarge  | F16s     | 16    | 32              | 64                    | (\$0.17)  | 127%        | (\$0.17)    | 113%        | (\$0.17)                 | 123%        | (\$0.17)                    | 102%        | (\$0.21)  | 128%        | (\$0.21)    | 114%        | (\$0.21)                 | 124%        | (\$0.21)                    | 103%        |
|                         | c5a.4xlarge  | F16s v2  | 16    | 32              | 128                   | (\$0.04)  | 107%        | \$0.07      | 95%         | (\$0.04)                 | 106%        | \$0.07                      | 99%         | (\$0.06)  | 108%        | (\$0.06)    | 104%        | (\$0.06)                 | 107%        | (\$0.06)                    | 101%        |
|                         | c5a.8xlarge  | F32s v2  | 32    | 64              | 256                   | (\$0.09)  | 107%        | \$0.14      | 95%         | (\$0.09)                 | 106%        | \$0.14                      | 99%         | (\$0.12)  | 108%        | (\$0.12)    | 104%        | (\$0.12)                 | 107%        | (\$0.12)                    | 101%        |
|                         | c5.12xlarge  | F48s v2  | 48    | 96              | 384                   | \$0.06  | 97%         | \$0.06      | 99%         | \$0.06                   | 97%         | \$0.06                      | 100%        | \$0.06  | 97%         | \$0.06      | 99%         | \$0.06                   | 98%         | \$0.06                      | 100%        |
| c5a.12xlarge            | F48s v2      | 48       | 96    | 384             | (\$0.13)              | 107%  | (\$0.13)    | 103%        | (\$0.13)    | 106%                     | (\$0.13)    | 101%                        | (\$0.18)    | 108%  | (\$0.18)    | 104%        | (\$0.18)    | 107%                     | (\$0.18)    | 101%                        |             |
| c5a.16xlarge            | F64s v2      | 64       | 128   | 512             | (\$0.17)              | 107%  | \$0.27      | 95%         | (\$0.17)    | 106%                     | (\$0.85)    | 103%                        | (\$0.24)    | 108%  | (\$0.24)    | 104%        | (\$0.24)    | 107%                     | (\$0.24)    | 101%                        |             |
| c5.18xlarge             | F72s v2      | 72       | 144   | 576             | \$0.09                | 97%   | \$0.59      | 91%         | \$0.09      | 97%                      | \$0.59      | 98%                         | \$0.09      | 97%   | \$0.09      | 99%         | \$0.09      | 98%                      | \$0.09      | 100%                        |             |
| Weighted Average ->     |              |          |       |                 |                       | 109.4%  |             | 100.8%      |             | 107.3%                   |             | 100.5%                      |             | 110.1%  |             | 105.2%      |             | 108.2%                   |             | 101.0%                      |             |

• For these comparisons AWS EBS storage pricing was factored in to determine hourly pricing for AWS instances

• With EBS is factored in, AWS instances appear to be marginally cheaper for all usage cases across Compute Optimized Instances with analogous specifications

# Identical Specification Comparisons

|  | Resources    |          |       |                 |                       | Commercial Services (Delta \$/Hr) \$[AWS - Azure] , [Azure/AWS]% |             |             |             |                          |             |                             |             | Government Services (Delta \$/hr) [AWS - Azure]\$, [Azure/AWS]% |             |             |             |                          |             |                             |             |        |      |
|--|--------------|----------|-------|-----------------|-----------------------|--|-------------|-------------|-------------|--------------------------|-------------|-----------------------------|-------------|---|-------------|-------------|-------------|--------------------------|-------------|-----------------------------|-------------|--------|------|
|  |              |          |       |                 |                       | Linux  |             | Windows     |             | Red Hat Enterprise Linux |             | Windows with SQL Enterprise |             | Linux   |             | Windows     |             | Red Hat Enterprise Linux |             | Windows with SQL Enterprise |             |        |      |
|  | AWS Instance | Azure VM | vCPUs | Memory (GiB/GB) | Instance Storage (GB) | Delta \$/Hr  | % Azure/AWS | Delta \$/Hr | % Azure/AWS | Delta \$/Hr              | % Azure/AWS | Delta \$/Hr                 | % Azure/AWS | Delta \$/Hr   | % Azure/AWS | Delta \$/Hr | % Azure/AWS | Delta \$/Hr              | % Azure/AWS | Delta \$/Hr                 | % Azure/AWS |        |      |
| Identical Specification (Various Categories) | m5d.8xlarge  | D32d v4  | 32    | 128             | 1200                  | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | m5d.xlarge   | D4d v4   | 4     | 16              | 150                   | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | m5d.xlarge   | D4ds v4  | 4     | 16              | 150                   | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | m5d.2xlarge  | D8d v4   | 8     | 32              | 300                   | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | m5d.2xlarge  | D8ds v4  | 8     | 32              | 300                   | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | m5d.4xlarge  | D16d v4  | 16    | 64              | 600                   | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | m5d.4xlarge  | D16ds v4 | 16    | 64              | 600                   | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | m5d.12xlarge | D48d v4  | 48    | 192             | 1800                  | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | m5d.12xlarge | D48ds v4 | 48    | 192             | 1800                  | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | m5d.16xlarge | D64d v4  | 64    | 256             | 2400                  | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | m5d.16xlarge | D64ds v4 | 64    | 256             | 2400                  | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | r5d.xlarge   | E4d v4   | 4     | 32              | 150                   | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | r5d.xlarge   | E4ds v4  | 4     | 32              | 150                   | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | r5d.2xlarge  | E8d v4   | 8     | 64              | 300                   | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | r5d.2xlarge  | E8ds v4  | 8     | 64              | 300                   | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | r5d.8xlarge  | E32ds v4 | 32    | 256             | 1200                  | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | r5d.12xlarge | E48d v4  | 48    | 384             | 1800                  | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
|  | r5d.12xlarge | E48ds v4 | 48    | 384             | 1800                  | \$0.00   | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00  | 100%        | \$0.00      | 100%        | \$0.00                   | 100%        | \$0.00                      | 100%        | \$0.00 | 100% |
| Weighted Averages->                          |              |          |       |                 | \$0.00                | 100%   | \$0.00      | 100%        | \$0.00      | 100%                     | \$0.00      | 100%                        | \$0.00      | 100%  | \$0.00      | 100%        | \$0.00      | 100%                     | \$0.00      | 100%                        | \$0.00      | 100%   |      |

- For these comparisons AWS instances have associated instance storage (no EBS was added)
- Instances/VMs with identical resources were observed to have identical pricing for General Purpose and Memory Optimized instances
  - Efficient Market Hypothesis in action between highly competitive companies with readily available pricing information

# Identical Specification – Raw Data Sample

Azure

Region: East US | Operating system: Linux | Type: Ubuntu | Tier: Standard

Category: All | Instance Series: All | INSTANCE: D32d v4 32 vCPUs, 128 GB RAM, 1200 GB Temporary storage \$1.808/...

Virtual machines: 1 x 730 Hours

Identical Hourly Pricing And Specifications

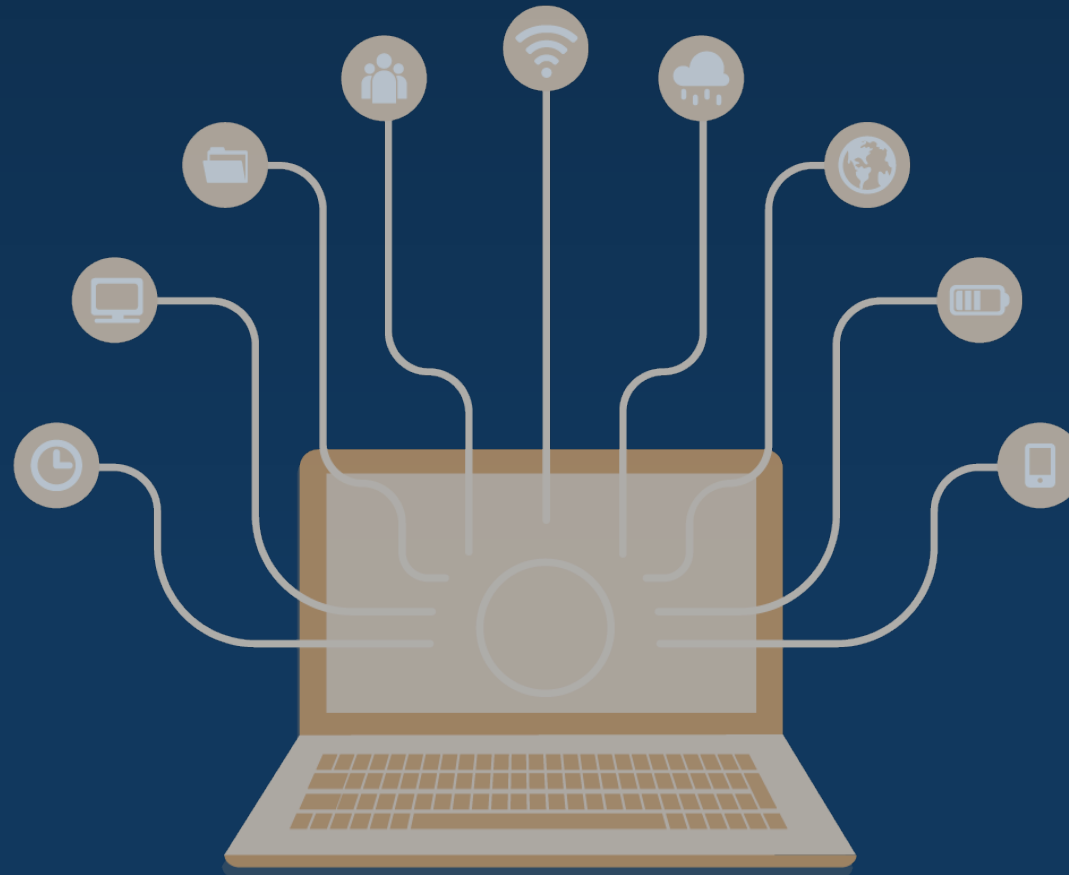
EC2 Instances (1)

Based on your inputs, this is the lowest-cost EC2 instance: **t4g.nano**

Chosen instance: **m5d.8xlarge** | Family: m5d | 32vCPU | 128 GiB Memory

| Instance name | vCPUs | Memory  | Network Per... | Storage          | On-Demand .. |
|---------------|-------|---------|----------------|------------------|--------------|
| m5d.8xlarge   | 32    | 128 GiB | 10 Gigabit     | 2 x 600 NVMe SSD | 1.808        |

# Conclusions and Key Takeaways





# Summary of Results

| Azure/AWS<br>Percent Comparison | Commercial Services |         |                             |                                |         | Government Services (NIPR) |         |                             |                                |         |
|---------------------------------|---------------------|---------|-----------------------------|--------------------------------|---------|----------------------------|---------|-----------------------------|--------------------------------|---------|
|                                 | Linux               | Windows | Red Hat<br>Enterprise Linux | Windows with<br>SQL Enterprise | Average | Linux                      | Windows | Red Hat<br>Enterprise Linux | Windows with<br>SQL Enterprise | Average |
| Identical Specifications        | 100.00%             | 100.00% | 100.00%                     | 100.00%                        | 100.00% | 99.99%                     | 100.00% | 100.00%                     | 100.00%                        | 100.00% |
| General Purpose                 | 95.24%              | 78.64%  | 96.14%                      | 95.84%                         | 91.46%  | 95.18%                     | 84.51%  | 96.11%                      | 96.52%                         | 93.08%  |
| Compute Optimized               | 109.41%             | 100.80% | 107.34%                     | 100.47%                        | 104.50% | 110.07%                    | 105.18% | 108.18%                     | 101.04%                        | 106.12% |
| Memory Optimized                | 107.02%             | 104.03% | 106.43%                     | 100.90%                        | 104.59% | 110.32%                    | 106.33% | 109.38%                     | 101.55%                        | 106.89% |

## Instance Categories Percent Comparisons

- Values are formatted as Azure/AWS cost
  - 95.24% means 'Azure is 4.76% cheaper than AWS for this instance/VM type on Average' within the dataset of analogous comparisons for Linux usage in General Purpose
  - 107.02% means 'Azure is 7.02% more expensive than AWS for this instance/VM type on Average' within the dataset of analogous comparisons for Linux usage in memory optimized instances
- For General Purpose, Compute, and Memory Optimized categories AWS instances EBS Storage cost was added to instance usage costs which may not be technically analogous to Azure temporary storage



## When can Cost matter?

- Instance/VM pricing should not be the starting point for deciding on a CSP; CSPs offer an ecosystem of services, the technical consequences of which must be informed by an expert
- When an expert has provided a scenario where the cost between CSPs should be investigated, the available pricing tools are an excellent resource when utilized properly
- Establishing a starting point to estimate an intricate cloud service effort should be done by direct analogy to an effort understood to be analogous by experts



# Resources and Fun Facts for Estimating Cloud Services

- Cloud Services come with many hidden costs. For a fantastic overview of these and the many “gotchas” that come when estimating cloud service costs consult “Comparing Cloud Costs Equitability – Overview (2018)” presented at ICEAA Workshop in 2019 by MITRE team
- For a primer on some available techniques for estimating Cloud Infrastructure consult “Estimating Cloud Infrastructure: Requirements, Methodologies, and Uncertainty Implementations” by Olivia Lindsey and Alex Smith, Quantech Services Inc. – ICEAA 2021 Online Workshop
- On Dec 7th 2022, the Joint Warfighting Cloud Capability (JWCC) contract was awarded to AWS, Google, Microsoft, and Oracle establishing a novel acquisition pathway shifting how mission critical Cloud Services may be obtained DoD wide



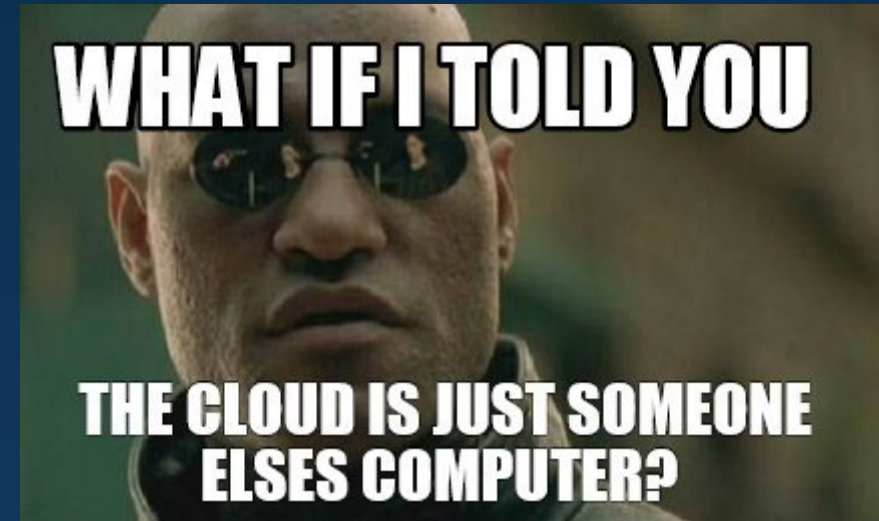
## Concluding Remarks

- **Pricing for Cloud Services is complex, but the instance/VM data present in CSP pricing calculators suggests that when considering identical specifications AWS and Azure are highly competitive.**
- **Navigating the nuances of pricing for Cloud Computing services requires a technically detailed understanding of precisely how those services will be provided**





Questions?



# Backup

# Memory Optimized

|                        | Resources    |          |       |                 |                       | Commercial Services (Delta \$/Hr) \$[AWS - Azure], [Azure/AWS]% |             |             |             |                          |             |                             |             | Government Services (Delta \$/hr) [AWS - Azure]\$, [Azure/AWS]% |             |             |             |                          |             |                             |             |
|------------------------|--------------|----------|-------|-----------------|-----------------------|---|-------------|-------------|-------------|--------------------------|-------------|-----------------------------|-------------|---|-------------|-------------|-------------|--------------------------|-------------|-----------------------------|-------------|
|                        |              |          |       |                 |                       | Linux   |             | Windows     |             | Red Hat Enterprise Linux |             | Windows with SQL Enterprise |             | Linux   |             | Windows     |             | Red Hat Enterprise Linux |             | Windows with SQL Enterprise |             |
|                        | AWS Instance | Azure VM | vCPUs | Memory (GiB/GB) | Instance Storage (GB) | Delta \$/Hr   | % Azure/AWS | Delta \$/Hr | % Azure/AWS | Delta \$/Hr              | % Azure/AWS | Delta \$/Hr                 | % Azure/AWS | Delta \$/Hr   | % Azure/AWS | Delta \$/Hr | % Azure/AWS | Delta \$/Hr              | % Azure/AWS | Delta \$/Hr                 | % Azure/AWS |
| Memory Optimized (EBS) | r5a.xlarge   | E4s v3   | 4     | 32              | 64                    | (\$0.02)  | 107%        | (\$0.02)    | 104%        | (\$0.02)                 | 106%        | (\$0.02)                    | 101%        | (\$0.04)  | 113%        | (\$0.04)    | 108%        | (\$0.04)                 | 111%        | (\$0.04)                    | 102%        |
|                        | r5.2xlarge   | E8s v3   | 8     | 64              | 128                   | \$0.02  | 97%         | \$0.02      | 98%         | \$0.02                   | 97%         | \$0.02                      | 100%        | (\$0.01)  | 102%        | (\$0.01)    | 101%        | (\$0.01)                 | 102%        | (\$0.01)                    | 100%        |
|                        | r5a.2xlarge  | E8s v3   | 8     | 64              | 128                   | (\$0.03)  | 107%        | (\$0.03)    | 104%        | (\$0.03)                 | 106%        | (\$0.03)                    | 101%        | (\$0.07)  | 113%        | (\$0.07)    | 108%        | (\$0.07)                 | 110%        | (\$0.07)                    | 102%        |
|                        | r5a.4xlarge  | E16s v3  | 16    | 128             | 256                   | (\$0.07)  | 107%        | (\$0.07)    | 104%        | (\$0.07)                 | 106%        | (\$0.07)                    | 101%        | (\$0.15)  | 113%        | (\$0.08)    | 104%        | (\$0.15)                 | 112%        | (\$0.08)                    | 101%        |
|                        | r5a.8xlarge  | E32s v3  | 32    | 256             | 512                   | (\$0.14)  | 107%        | (\$0.14)    | 104%        | (\$0.14)                 | 107%        | (\$0.14)                    | 101%        | (\$0.29)  | 113%        | (\$0.15)    | 104%        | (\$0.29)                 | 112%        | (\$0.15)                    | 101%        |
|                        | r5.12xlarge  | E48 v3   | 48    | 384             | 1200                  | \$0.16  | 95%         | \$0.16      | 97%         | \$0.16                   | 95%         | \$0.16                      | 99%         | \$0.20  | 95%         | \$0.20      | 97%         | \$0.20                   | 95%         | \$0.20                      | 99%         |
|                        | r5.12xlarge  | E48s v3  | 48    | 384             | 768                   | \$0.11  | 97%         | \$0.11      | 98%         | \$0.11                   | 97%         | \$0.11                      | 100%        | \$0.13  | 97%         | \$0.13      | 98%         | \$0.13                   | 97%         | \$0.13                      | 99%         |
|                        | r5a.12xlarge | E48 v3   | 48    | 384             | 1200                  | (\$0.15)  | 105%        | (\$0.15)    | 103%        | (\$0.15)                 | 105%        | (\$0.15)                    | 101%        | (\$0.16)  | 105%        | (\$0.16)    | 103%        | (\$0.16)                 | 105%        | (\$0.16)                    | 101%        |
|                        | r5a.12xlarge | E48s v3  | 48    | 384             | 768                   | (\$0.21)  | 107%        | (\$0.21)    | 104%        | (\$0.21)                 | 107%        | (\$0.21)                    | 101%        | (\$0.23)  | 107%        | (\$0.23)    | 104%        | (\$0.23)                 | 107%        | (\$0.23)                    | 101%        |
|                        | r5.16xlarge  | M64ls    | 64    | 512             | 2048                  | (\$1.10)  | 126%        | (\$1.10)    | 115%        | (\$1.10)                 | 125%        | (\$1.10)                    | 104%        | (\$1.33)  | 126%        | (\$1.92)    | 124%        | (\$1.33)                 | 125%        | (\$1.92)                    | 106%        |
| Weighted Average ->    |              |          |       |                 |                       | 107.0%  |             | 104.0%      |             | 106.4%                   |             | 100.9%                      |             | 110.3%  |             | 106%        |             | 109.4%                   |             | 101.5%                      |             |

- For these comparisons AWS EBS storage pricing was factored in to determine hourly pricing for AWS instances
- With EBS is factored in, AWS instances appear to be marginally cheaper for all usage cases across Memory Optimized Instances with analogous specifications
- Memory Optimized instances exhibit the lowest variation in % Azure/AWS across all use cases for



# General Purpose

|                       | Resources    |          |       |                 |                       | Commercial Services (Delta \$/Hr) \$[AWS - Azure] , [Azure/AWS]% |             |             |             |                          |             |                             |             | Government Services (Delta \$/hr) [AWS - Azure]\$, [Azure/AWS]% |             |             |             |                          |             |                             |             |
|-----------------------|--------------|----------|-------|-----------------|-----------------------|--|-------------|-------------|-------------|--------------------------|-------------|-----------------------------|-------------|---|-------------|-------------|-------------|--------------------------|-------------|-----------------------------|-------------|
|                       |              |          |       |                 |                       | Linux  |             | Windows     |             | Red Hat Enterprise Linux |             | Windows with SQL Enterprise |             | Linux   |             | Windows     |             | Red Hat Enterprise Linux |             | Windows with SQL Enterprise |             |
|                       | AWS Instance | Azure VM | vCPUs | Memory (GiB/GB) | Instance Storage (GB) | Delta \$/Hr  | % Azure/AWS | Delta \$/Hr | % Azure/AWS | Delta \$/Hr              | % Azure/AWS | Delta \$/Hr                 | % Azure/AWS | Delta \$/Hr   | % Azure/AWS | Delta \$/Hr | % Azure/AWS | Delta \$/Hr              | % Azure/AWS | Delta \$/Hr                 | % Azure/AWS |
| General Purpose (EBS) | m5.xlarge    | B4ms     | 4     | 16              | 32                    | \$0.03   | 85%         | \$0.20      | 48%         | \$0.03                   | 88%         | \$0.20                      | 89%         | \$0.05  | 79%         | \$0.20      | 53%         | \$0.05                   | 83%         | \$0.20                      | 89%         |
|                       | m5.xlarge    | D4 v3    | 4     | 16              | 100                   | \$0.01   | 93%         | \$0.01      | 96%         | \$0.01                   | 95%         | \$0.01                      | 99%         | \$0.01  | 97%         | \$0.01      | 99%         | \$0.01                   | 98%         | \$0.01                      | 100%        |
|                       | m5.2xlarge   | B8ms     | 8     | 32              | 64                    | \$0.06   | 85%         | \$0.40      | 48%         | \$0.06                   | 89%         | \$0.40                      | 89%         | \$0.10  | 79%         | \$0.31      | 64%         | \$0.10                   | 83%         | \$0.31                      | 92%         |
|                       | t3a.2xlarge  | B8ms     | 8     | 32              | 64                    | (\$0.02)   | 108%        | \$0.09      | 80%         | (\$0.02)                 | 105%        | \$0.09                      | 97%         | (\$0.03)  | 108%        | (\$0.04)    | 108%        | (\$0.03)                 | 106%        | (\$0.04)                    | 101%        |
|                       | m5.4xlarge   | B16ms    | 16    | 64              | 128                   | \$0.12   | 85%         | \$0.79      | 48%         | \$0.12                   | 87%         | \$0.79                      | 89%         | \$0.21  | 79%         | \$0.88      | 49%         | \$0.21                   | 81%         | \$0.88                      | 89%         |
|                       | m5a.4xlarge  | B16ms    | 16    | 64              | 128                   | \$0.04   | 94%         | \$0.71      | 51%         | \$0.04                   | 95%         | \$0.71                      | 90%         | \$0.11  | 87%         | \$0.79      | 52%         | \$0.11                   | 89%         | \$0.79                      | 90%         |
|                       | m5.8xlarge   | D32s v3  | 32    | 128             | 256                   | \$0.04   | 98%         | \$0.04      | 99%         | \$0.04                   | 98%         | \$0.04                      | 100%        | (\$0.04)  | 102%        | (\$0.04)    | 101%        | (\$0.04)                 | 102%        | (\$0.04)                    | 100%        |
|                       | m5a.8xlarge  | D32s v3  | 32    | 128             | 256                   | (\$0.12)   | 109%        | (\$0.12)    | 104%        | (\$0.12)                 | 108%        | (\$0.12)                    | 101%        | (\$0.23)  | 113%        | (\$0.23)    | 107%        | (\$0.23)                 | 112%        | (\$0.23)                    | 102%        |
|                       | m5.12xlarge  | D48s v3  | 48    | 192             | 384                   | \$0.05   | 98%         | \$0.05      | 99%         | \$0.05                   | 98%         | \$0.05                      | 100%        | (\$0.06)  | 102%        | (\$0.06)    | 101%        | (\$0.06)                 | 102%        | (\$0.06)                    | 100%        |
|                       | m5.16xlarge  | D64s v3  | 64    | 256             | 512                   | \$0.07   | 98%         | \$0.07      | 99%         | \$0.07                   | 98%         | \$0.07                      | 100%        | (\$0.08)  | 102%        | (\$0.08)    | 101%        | (\$0.08)                 | 102%        | (\$0.08)                    | 100%        |
| Weighted Average ->   |              |          |       |                 |                       |  |             |             |             |                          |             |                             |             |   |             |             |             |                          |             |                             |             |
|                       |              |          |       |                 |                       | 95.2%  |             | 78.6%       |             | 96.1%                    |             | 95.8%                       |             | 95.2%   |             | 84.5%       |             | 96.1%                    |             | 96.5%                       |             |

- For these comparisons AWS EBS storage pricing was factored in to determine hourly pricing for AWS instances
- With EBS is factored in, AWS instances appear to be marginally cheaper for all usage cases across General Purpose Instances with analogous specifications
- If AWS VMs could be utilized with a bit less EBS instance storage, prices would be comparable for all use cases except Windows

## Resources for learning about Cloud Estimating and Cost Savings

- Estimating Cloud Infrastructure (ICEAA 2020)
  - Olivia Lindsey and Alex Smith – Quantech Services Inc.
  - <https://www.iceaaonline.com/wp-content/uploads/2021/06/CYC04-ppt-Lindsey-Estimating-Cloud-Infrastructure.pdf>
- Comparing Cloud Costs Equitability – Overview (ICEAA 2018)
  - Kevin Buck, John Dubelko, Matt Griesbach and Anthony Rojas – MITRE
  - <https://www.iceaaonline.com/wp-content/uploads/2019/06/CC01-Comparing-Cloud-Clost-Buck.pdf>
- Realizing the Financial Value of Cloud (When does cloud realize cost savings)
  - Gaurav Aggarwal – Forbes Technology Council
  - <https://www.forbes.com/sites/forbestechcouncil/2021/05/03/realizing-the-financial-value-of-cloud/?sh=5ab566203467>



## Resources for Cloud Pricing and General Cloud Information

- AWS vs Azure: Comparing the Cloud Computing Giants
  - Edward Jones: <https://kinsta.com/blog/aws-vs-azure/>
- AWS Pricing Calculator
  - <https://calculator.aws/>
- Azure Pricing Calculator
  - <https://azure.microsoft.com/en-us/pricing/calculator/>
- Google Cloud Pricing Calculator
  - <https://cloud.google.com/products/calculator>
- Oracle Cloud Pricing Calculator
  - <https://www.oracle.com/in/cloud/costestimator.html>