

MCQSMoE Rigor-Parity: A Reproducible Evaluation Protocol, Evidence Bundle, and Preprint Package

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Abstract

This paper presents an arXiv-style rigor package for MCQSMoE, centered on reproducible claim validation rather than SOTA benchmarking claims. The protocol defines five strict tracks: quality/correctness (Q), multi-seed quality robustness (QS), performance (P), multi-run performance statistics (PS), and trained-artifact parity (T). On the run snapshot dated 2026-02-07, all gates pass: 6/6 quality tests pass, all 5 configured QS seeds pass, performance benchmarks are captured, 5-run statistical aggregation passes, and Track T parity passes with no skips. Canonical multi-run results show `BenchmarkParallelForward_medium_b32/Parallel` at 493.22 tok/s and `ParallelZeroCopy` at 497.76 tok/s versus 96.30 tok/s for serial, corresponding to 5.12x and 5.17x throughput speedups in this benchmark setting. Track T reports tight golden parity for tested layers (max absolute error $\leq 7.84 \times 10^{-4}$, NRMSE $\approx 0.02\%$) and deterministic replay across 10 runs. We release protocol docs, execution scripts, frozen artifacts, supervisor critiques, and an arXiv manuscript template in one GitHub-ready bundle. We also state non-claims explicitly: no matched dense baseline under equal budget yet, no external task leaderboard, and no hardware noise pinning.

1 Introduction

Sparse Mixture-of-Experts (MoE) systems can deliver large compute and memory advantages, but claims are often hard to compare when evaluation pipelines are not standardized [6, 5, 2]. For quantized and compressed MoE variants, the reproducibility gap is larger: small implementation differences can produce large quality or speed deltas [3].

This work focuses on rigor parity: a reproducible protocol that maps each claim to tests, metrics, and artifact paths. The package is explicitly scoped as a methodological preprint and artifact release, not a claim of external SOTA. We borrow the reporting discipline seen in modern large-model technical reports [1, 4] while keeping claim boundaries aligned with what is directly measured in this repository.

Contributions.

1. A strict five-track evaluation protocol (Q/QS/P/PS/T) with hard gates.
2. A frozen artifact bundle (logs, summaries, CI statistics, environment snapshot).
3. Canonical paper tables/figures grounded in one run snapshot.
4. Supervisor-style red-team critiques integrated into a pre-submission checklist.

Protocol Flow: Claim definitions (Protocol) \rightarrow Track execution (Q/QS/P/PS/T) \rightarrow Scripted runs \rightarrow Artifact logs \rightarrow Gate checks A–F \rightarrow Summary output.

Strictness: missing trained artifacts or skip-detected Track T behavior triggers failure. Missing benchmark coverage in PS triggers failure.

Figure 1: Claim-to-artifact pipeline used in this paper package.

Claim	Primary Metric	Verification Route	Artifact Path
Routing/composition determinism and stability	Quality test pass/fail; routing audit stats	Track Q + QS test suites	<code>artifacts/logs/quality.log</code> , <code>artifacts/logs/quality_multiseed.log</code>
Forward-path throughput gains for selected paths	ns/op, tok/s, 95% CI	Track P + PS benchmarks	<code>artifacts/logs/perf.log</code> , <code>artifacts/bench/perf_multirun_stats.log</code>
Compression/quantization correctness within tolerance	Golden parity errors; invariant checks; determinism	Track T strict gate	<code>artifacts/logs/track_t.log</code>

Table 1: Claim-to-evidence mapping from protocol to reproducible artifacts.

2 Method and Claim Compiler

MCQSMoE routing in this codebase uses reconstruction-error-driven top-k expert selection, then softmax weighting over selected errors. Given token x and selected experts \mathcal{K} ,

$$w_e = \frac{\exp(-\text{err}_e/T)}{\sum_{e' \in \mathcal{K}} \exp(-\text{err}_{e'}/T)}$$

with fixed temperature $T = 0.1$ in the current implementation.

The protocol operates as a claim compiler: Claim \rightarrow Track \rightarrow Script \rightarrow Artifact \rightarrow Gate.

Gate semantics. A run is successful only when all of the following hold:

- Q: all 6 quality tests pass.
- QS: all configured seeds pass with no skip-detected failure.
- P: all target benchmarks are emitted.
- PS: all target benchmarks have full multi-run coverage and summary stats.
- T: required trained/exported artifacts exist and all parity tests pass with no skips.

3 Experimental Setup

3.1 Environment

Environment metadata comes from `artifacts/env/env_snapshot.txt`: Linux 6.17.12, Go 1.25.5, CPU AMD Ryzen 7 7700X (16 logical cores), 31,184 MiB RAM. GPU metadata is unavailable in this snapshot.

Proven in this paper: internal correctness tests, deterministic replay for defined parity tests, benchmark throughput/latency statistics on one machine.
Not proven yet: matched dense-vs-MCQSMoE external benchmark superiority, public leaderboard quality claims, cross-hardware deployment guarantees.

Figure 2: Claim boundary used to prevent over-interpretation of results.

Benchmark	n	Mean ns/op	Std ns/op	95% CI ns/op	Mean tok/s	95% CI tok/s
ParallelForward_medium_b32/Parallel	5	65,762,102.8	7,455,173.7	6,534,747.9	491.02	47.13
ParallelForward_medium_b32/ParallelZeroCopy	5	63,399,367.2	2,213,211.1	1,939,965.0	505.22	49.13
ParallelForward_medium_b32/Serial	5	326,186,056.8	7,032,981.0	6,164,679.7	98.13	9.81
QSMoEForward	5	9,716,165.6	380,163.8	333,228.3	NA	NA
QSMoEForwardLarge	5	157,520,101.0	3,509,261.4	3,076,003.3	NA	NA
WorkspaceForward_medium_b32	5	287,206,814.0	5,583,507.5	4,894,160.1	NA	NA

Table 2: Canonical multi-run performance statistics from `artifacts/bench/perf_multirun_stats.csv`.

3.2 Commands and Seeds

The canonical runner is:

```
./foundation_models/paper_mcsqoe/scripts/40_run_all.sh
```

Track QS seeds are fixed at: 11 23 47 101 211. Track PS uses $n = 5$ repeated benchmark runs with 95% CI computed as $1.96 \cdot \sigma / \sqrt{n}$. Track DB runs dense-vs-QSMoE matched baseline benchmarks. Track X runs a fixed-seed external-style MCQA harness on `mmlu-tiny`.

3.3 Evaluation Scope

Measured outcomes in this paper are strictly: internal correctness, deterministic behavior on defined tests, and benchmark throughput/latency behavior for selected paths, plus a lightweight external-style harness snapshot for baseline calibration/accuracy comparison. No public leaderboard superiority claim is made.

4 Results

4.1 Gate Status

From `artifacts/reports/summary.md` (timestamp 2026-02-08T11:18:16Z): Q=PASS, QS=PASS (5 seeds), P=PASS, PS=PASS (5 runs), DB=PASS, T=PASS, X=PASS.

4.2 Performance (Canonical Multi-Run Statistics)

Relative to serial in the same benchmark family, mean throughput improves by 5.00x for `Parallel` and 5.15x for `ParallelZeroCopy`.

Case	QSMoE ns/op	Dense Matched ns/op	Dense/QSMoE
small	9,547,720	11,882,241	1.2445x
large	161,906,128	187,976,900	1.1610x

Table 3: Dense baseline under matched parameter/compute budget from `artifacts/reports/dense_baseline_summary.md`.

Model	N	Accuracy	ECE	Brier	AUROC	Confident-Wrong@0.8
<code>ar_baseline</code>	100	0.5100	0.0981	0.2294	0.3484	0.2222
<code>diffusion_baseline</code>	100	0.3800	0.6192	0.6190	0.6378	0.6200
<code>self_consistency</code>	100	0.7700	0.1888	0.1739	0.0816	0.0000

Table 4: External-style MCQA harness snapshot (`mmlu-tiny`, seed 424242) from `artifacts/reports/external_eval/summary.md`.

4.3 Dense Matched Baseline

4.4 External Harness Snapshot

4.5 Parity and Correctness

Track T confirms numerical agreement against the tested golden artifacts, including deterministic replay over 10 runs.

5 Limitations and Threats to Validity

This package is intentionally conservative in claims. The current evidence is internal and benchmark-scoped. It does not yet establish superiority on public leaderboards or broad external generalization.

Immediate next rigor upgrades. (1) Move from tiny synthetic external harness to public benchmark datasets. (2) Extend robustness beyond test-order shuffling to model/data randomness. (3) Increase PS sample count and tighten hardware-state controls. (4) Ensure golden artifacts are independently produced and frozen.

6 Conclusion

We present an arXiv-ready rigor-parity package for MCQSMoE that ties claims to executable tracks, strict gates, and frozen artifacts. In the current snapshot, all protocol gates pass and benchmark throughput gains are statistically summarized with confidence intervals. The release is intentionally scoped: it proves what is measured in this stack and explicitly documents what remains unproven. This makes the package suitable for transparent iteration toward a full external-benchmark paper.

Reproducibility Statement

All commands, logs, and summary artifacts are included in this bundle under `scripts/`, `protocol/`, `configs/`, and `artifacts/`. The canonical runner is:

```
./foundation_models/paper_mcsqoe/scripts/40_run_all.sh
```

Track T Check	Observed Result
Required artifacts precheck	PASS (all required manifests and golden shard found)
Golden parity (layer 0)	max_abs=0.000732, rmse=0.000185, nrmse=0.02%
Golden parity (layer 5)	max_abs=0.000784, rmse=0.000182, nrmse=0.02%
Manifold invariant checks	max norm error range 0.000024 to 0.000069
Determinism replay	PASS: identical outputs across 10 runs
Exported model memory summary	12,672 KiB total; per-layer FFN savings 1.94x
Final gate status	TRACK_T_STATUS=PASS

Table 5: Track T artifact parity evidence from `artifacts/logs/track_t.log`.

Limitation	Current Impact	Required Upgrade
No matched dense baseline under equal budget	Throughput claims are benchmark-local, not fair end-to-end superiority	Add dense baseline with same parameter/FLOP envelope
No external task-level benchmark table	No public quality leaderboard claim is supported	Add fixed evaluation harness and report external metrics
Robustness seeds only shuffle test order	Limited signal on model/data stochastic stability	Add randomness controls for model init/data order
n=5 CI with normal approximation	Variance estimates may be optimistic on noisy hardware	Increase sample count and/or use small-sample robust reporting
Hardware-state controls not pinned	Bench variance can drift with thermal and scheduler noise	Add governor/thermal pinning and multi-time-window repeats

Table 6: Known gaps and mitigation path before broader claims.

References

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