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THE ASSET SPECIFICITY TRAP: REFINERY COMPLEXITY AND STRATEGIC ADAPTATION IN ASIA DURING THE 2026 GULF ENERGY CRISIS

Kameleddine Benameur

Department of Accounting, Finance and Economics, College of Business and Economics
American University of Kuwait, Salmiya, Kuwait
Email: kbenameur@auk.edu.kw

Ralph Palliam

Department of Accounting, Finance and Economics, College of Business and Economics
American University of Kuwait, Salmiya, Kuwait
Email: rpalliam@auk.edu.kw

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Abstract

The 2026 disruption of oil and gas flows through the Strait of Hormuz exposed a strategic vulnerability that is often obscured by conventional measures of energy security: access to replacement barrels does not necessarily imply that downstream assets can process them efficiently. This study examines how refinery configuration shaped adaptation across four Asian cases—India, South Korea, Vietnam, and Pakistan—during the disruption. Drawing on Transaction Cost Economics, the paper treats refinery assets as highly specific commitments, while using refinery complexity as an indicator of embedded operational optionality rather than as a direct inverse measure of specificity. A comparative multiple-case design traces two distinct adaptation pathways. Highly complex refining systems relied more heavily on internal reconfiguration, product-slate flexibility, and diversified procurement. Lower-complexity systems also adapted, but relied more on emergency sourcing, inventory drawdown, imported products, and public or macroeconomic buffers. The central finding is not that complexity determines survival. Rather, complexity influences how adaptation occurs and where its costs are recorded. The paper contributes the concept of adaptation-cost location, which is developed as an interpretive construct drawn from the comparative case evidence. Building on this construct, the paper proposes a complexity-adjusted supply-risk disclosure framework for strategic management accounting; this framework is

offered as a normative implication for practice rather than as a management accounting mechanism directly observed in the four cases. It also identifies joint stockpiling and geographically distributed storage as lower-capital substitutes for immediate refinery upgrading in vulnerable importing economies.

Keywords

Asset Specificity, Refinery Complexity, Strategic Flexibility, Supply-Chain Resilience, Strategic Management Accounting; Strait of Hormuz.

Introduction

Geopolitical disruptions are usually analyzed as shocks to the volume, price, or route of energy supply (Chesnes, 2015). Such measures are necessary but incomplete. In refining, crude oil is not a homogeneous input: differences in density, sulfur content, acidity, metals, and distillation yield interact with the configuration of each refinery. A replacement cargo can therefore be commercially available yet operationally costly, yield an undesirable product mix, or require blending and conversion capacity that a refinery does not possess. The 2026 Gulf energy crisis made this mismatch visible by simultaneously constraining maritime access, raising insurance and freight costs, and forcing Asian refiners to search for non-traditional feedstocks under severe time pressure (United Nations Conference on Trade and Development, 2026).

The strategic problem is particularly important in Asia because the region combines high dependence on imported crude with substantial variation in refinery configuration, fiscal capacity, strategic stocks, and market structure (Kellner, 2012). Some hubs operate deep-conversion refineries capable of processing a broad range of crude qualities and shifting output between products (Kim, 2015). Others rely on simpler hydro-skimming or medium-conversion configurations that are more dependent on a narrower crude slate. The same external shock can therefore create very different managerial problems across otherwise import-dependent economies.

This paper develops a business-strategy interpretation of that divergence. Transaction Cost Economics (TCE) explains why firms become vulnerable when specialized, immobile assets are tied to established supply relationships. However, refinery complexity complicates a simple lock-in argument. Complex refineries are themselves highly specialized and capital intensive, yet their conversion units may create operational options that reduce the cost of changing crude slates or product yields. Complexity should therefore not be treated as the opposite of asset specificity. It is better understood as embedded optionality inside a highly specific asset base (Harada, 2026; Shao & An, 2022).

The paper asks: How does refinery complexity influence the mechanism and distribution of adaptation costs when a geopolitical chokepoint disrupts established crude-supply relationships? The empirical analysis compares four cases—India, South Korea, Vietnam, and Pakistan—selected to capture contrasts in refinery complexity and adaptation mechanisms while holding the broad external shock constant. The analysis does not claim causal identification from a small sample. Instead, it uses theory-guided process tracing to examine how firms and governments kept fuel flowing and where the economic burden of adaptation appeared.

The findings revise the strongest version of the initial asset-specificity proposition. Low-complexity systems did not necessarily fail operationally; several maintained refinery runs or domestic fuel availability through emergency procurement and inventory measures. The difference was the form and location of the cost. Higher-complexity systems were better positioned to absorb adjustment through internal product-slate changes and broader crude compatibility. Lower-complexity systems depended more heavily on external sourcing, strategic stocks, imported products, and national financial buffers. This distinction motivates the paper's central concept: adaptation-cost location—the organizational or economic level at which the cost of maintaining continuity is ultimately recorded.

The study makes three contributions. First, it separates asset specificity from operational optionality and shows how both can coexist in the same physical asset. Second, it extends TCE from the question of governance choice to the question of adaptation under irreversible capital commitments. Third, it positions strategic management accounting (SMA) as a disclosure and decision framework that follows from the empirical findings as a recommendation for practice. SMA is not treated as an explanatory variable in the case analysis. No internal accounting system, managerial dashboard, or investment appraisal process was directly observed in any of the four cases; accordingly, the study makes no claims regarding their existence or use.

Theoretical Background and Hypotheses

Asset Specificity and Maladaptation Under Supply Disruption

TCE argues that specific investments create quasi-rents, switching costs, and exposure to maladaptation when the surrounding transaction environment changes (Williamson, 2010). Refineries display several forms of specificity. Physical specificity arises from process units designed around expected crude qualities and product specifications. Site specificity arises from ports, pipelines, storage systems, and proximity to established suppliers and customers. Temporal specificity arises because crude supply, refinery scheduling, and product delivery must be coordinated continuously; even a technically feasible substitution may arrive too late to prevent run cuts or inventory shortages.

Traditional TCE often focuses on governance responses such as vertical integration, long-term contracts, or relational safeguards (Hennart & Verbeke, 2022). In a sudden chokepoint shock, however, firms cannot redesign their physical assets or contractual architecture immediately. The relevant problem becomes ex post adaptation: finding alternative crude, modifying blends, changing unit severity, reallocating product output, drawing inventories, or purchasing finished products. The cost of these actions is shaped by the pre-existing asset configuration and by complementary capabilities outside the refinery gate (Lumineau et al., 2022).

Refinery Complexity as Embedded Operational Optionality

The Nelson Complexity Index (NCI) is commonly used to compare the relative capital intensity and secondary processing capability of refineries (Nelson, 1976; Hackett et al., 2013). A higher index generally indicates a larger set of conversion and upgrading units, such as catalytic cracking, hydrocracking, coking, and desulfurization. These units do not make a refinery unspecialized. On the contrary, they represent highly specific investments. Yet they can create a broader feasible set of crude slates and product-yield responses than a simple topping or hydro-skimming refinery (Öhlinger et al., 2024). NCI should not be

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read as a universal proxy for total refinery agility. The index summarizes the capital intensity and range of secondary processing units on a common scale, but it does not capture regional crude-slate constraints, pipeline and port access, hydrogen availability, logistics bottlenecks, or maintenance status, each of which can widen or narrow the feasible response set independently of the index value. Two refineries with similar NCI scores can therefore face materially different adaptation options depending on these localized, non-indexed factors. Throughout this paper, NCI is used only as an indicator of embedded conversion capacity, and case-level qualitative evidence is used to establish the actual response set in each instance.

This distinction resolves an apparent theoretical contradiction (Shao & An, 2022). Asset specificity concerns the sink and transaction-specific character of the investment. Operational optionality concerns the range of actions available once the investment is in place. A refinery can therefore be simultaneously more asset-specific and more adaptable. The strategic value of complexity lies not in eliminating lock-in, but in changing the consequences of lock-in when the input environment shifts. This pattern is consistent with broader literature showing that governance choices and contextual moderators, rather than specificity alone, shape performance and resilience outcomes in asset-specific relationships (Guo et al., 2023; Luo & Chen, 2023; Tennakoon et al., 2025; Avdasheva & Geliskhanov, 2025).

Strategic Management Accounting and Adaptation-Cost Visibility

SMA emphasizes externally oriented, forward-looking information for strategic decisions (Hoque, 2001; Suarez, 2022). In the present context, its relevance lies in making adaptive options and their cost consequences visible before a disruption occurs. Scenario costing can compare the effect of alternative crude slates on feedstock cost, energy use, hydrogen demand, product yield, working capital, and logistics. Strategic investment appraisal can compare conversion-unit upgrades with storage, supply contracts, or joint-stockpiling arrangements. Value-chain analysis can trace whether the cost of adaptation is absorbed inside the refinery or transferred to governments, importers, consumers, and the financial system (Nartey, 2024).

The case evidence does not directly observe internal accounting systems, managerial dashboards, or investment-appraisal practices. SMA is therefore used as a normative and interpretive framework rather than as a measured mediator (Weber & Coff, 2024). The empirically observed construct is adaptation-cost location. This is defined as the principal level at which continuity costs become visible: firm-level operating and capital decisions, supply-chain partners, public inventories, the trade account, the exchange rate, or consumer prices.

Propositions

The comparative analysis is guided by two propositions:

> ***Proposition 1:*** *Greater refinery complexity expands the set of internal operational responses available after a crude-supply disruption, even though the refinery remains a highly specific asset.*
>
> ***Proposition 2:*** *Where internal operational optionality is limited, continuity is more likely to depend on external procurement, strategic stocks, imported products, and public macroeconomic buffers; adaptation costs will therefore be more visible outside the firm.*

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Methodology

Research Design and Unit of Analysis

The study uses an embedded comparative multiple-case design. The primary unit of analysis is the refining system responding to the 2026 Gulf supply disruption. Each case includes three nested levels: the refinery or refining hub, the firm or state-owned enterprise making operational decisions, and the national institutions that provide inventories, foreign exchange, subsidies, or emergency procurement support. This multi-level structure is necessary because the paper's principal outcome—adaptation-cost location—can move across organizational boundaries.

The design supports analytic rather than statistical generalization. It is intended to identify mechanisms and refine theory, not estimate a population-level effect of NCI. Claims are therefore framed as pattern matching and theoretically informed interpretation. No regression results are used as confirmatory evidence.

Case Selection

Cases were selected for theoretical contrast. India's Jamnagar complex represents a highly complex, deep-conversion refining hub with substantial scale and product flexibility. South Korea represents a complex national refining system supported by sophisticated logistics and strategic stocks. Vietnam's Nghi Son refinery represents a facility with a more constrained crude relationship and a narrower set of immediate internal options. Pakistan represents a refining system dominated by relatively simple and medium-conversion plants operating under tighter balance-of-payments and fiscal constraints. The cases are not matched on size or macroeconomic structure; those differences are treated as contextual conditions rather than assumed away.

Data and Triangulation

The analysis covers the disruption beginning in late February 2026 through the latest consistently documented observations available at the time of writing (July 2026); all sources and figures dated 2026 are drawn from within this window and are treated as provisional pending final-year data revisions. Because the event remained recent at the time of writing, all 2026 figures are treated as provisional and subject to revision. Evidence was assembled from international energy reports (International Energy Agency, 2026a–2026f), company disclosures, national statistics, strategic-reserve announcements, refinery-profile sources, and contemporaneous business reporting. Open datasets, including JODI oil statistics (Joint Organisations Data Initiative, 2026), UN Comtrade (United Nations, 2026), IMF macroeconomic series (International Monetary Fund, 2026), and PortWatch maritime indicators (International Monetary Fund & University of Oxford Environmental Change Institute, 2026), are used where possible to cross-check the direction and timing of reported changes.

Cargo-level and crude-slate information is often available only through proprietary vessel-tracking providers such as Kpler and Vortexa. The paper therefore does not present unidentified or unattributed voyage-tracking indices as independent validation and does not report small-sample cross-country regressions as confirmatory evidence: with only four to six Asian economies for which comparable complexity and outcome measures exist, and with national inflation and trade outcomes confounded by exchange-rate policy, subsidy design, and fiscal capacity, such estimates would carry a false sense of

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statistical precision. The comparative case evidence in "Findings" section is therefore the paper's primary empirical basis.

Analytical Procedure

For each case, the analysis follows four steps. First, it describes the pre-shock refinery configuration and supply relationship. Second, it identifies the operational and procurement responses taken during the disruption. Third, it assesses whether those responses were primarily internal to the refinery or dependent on external institutions and markets. Fourth, it identifies where the resulting cost became visible. Cross-case comparison then tests whether the observed pattern is consistent with the two propositions.

The paper does not estimate refinery-specific product-yield changes from generic assay tables. Such calculations require detailed crude assays, unit constraints, operating severity, and optimization models that are not publicly available on a consistent basis. Technical claims are therefore limited to the general proposition, well established in refinery engineering, that conversion and upgrading capacity expands the range of economically feasible crude and product responses.

Limitations

The design has four principal limitations. First, four cases cannot establish a general causal effect of complexity. Second, published NCI values are not equally transparent across all refineries and vintages. Third, country-level outcomes are affected by subsidies, exchange rates, fiscal space, inventory policy, and market structure in addition to refinery configuration. Fourth, the shock was recent and some data remained provisional. These limitations require cautious language: the evidence is interpreted as consistent with the proposed mechanisms, not as proof that refinery complexity alone caused the observed outcomes.

Findings

India: Internal Reconfiguration at a Highly Complex Hub

The Jamnagar refining complex illustrates the strategic value of embedded operational optionality. Its very high complexity reflects extensive secondary processing capacity and a broad ability to alter crude blends and product yields. During the disruption, public reporting indicated that the complex maintained operational flexibility while responding to shortages in selected products. The most frequently cited example was a substantial increase in LPG output, reported in industry and financial press rather than in a primary company filing; the precise multiple is therefore treated here as indicative of the direction and scale of the response rather than as an audited figure.

The case is important not because it proves that NCI mechanically produces a particular product response, but because it shows the type of response a complex configuration can make feasible. Adjustments can occur through internal scheduling, blending, conversion, and product-slate choices rather than solely through emergency imports of finished fuel. The economic burden is therefore more likely to appear in the firm's operating decisions, margins, energy use, working capital, and opportunity costs. Those costs may still be substantial, but they are more controllable and more readily incorporated into enterprise decision processes.

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South Korea: Complexity Combined with Strategic Logistics

South Korea’s response demonstrates that refinery complexity is most effective when paired with complementary institutions. Korean refiners operate sophisticated conversion and desulfurization assets, but their resilience also depended on strategic reserves, diversified procurement, storage, and state coordination. The emergency release of crude stocks and the use of producer-linked storage arrangements at Ulsan provided a buffer while firms widened their supply base.

This is not a pure refinery-complexity case. It is a system-capability case. Internal technical flexibility reduced the risk that alternative barrels would be unusable or economically unattractive, while national inventories and contracting arrangements reduced the timing risk of obtaining them. The resulting cost was shared between firms and the state, but the system avoided relying exclusively on spot-market product imports or abrupt domestic demand destruction. South Korea therefore supports a broader formulation of Proposition 1: complexity creates options, but complementary logistics and governance determine whether those options can be exercised quickly.

Vietnam: Continuity Through Emergency Sourcing

Vietnam’s Nghi Son refinery had a historically close relationship with Kuwaiti crude and a more constrained immediate operating envelope than the highly complex comparator cases. The disruption did not produce the complete operational collapse that a deterministic asset-lock-in argument would predict. Instead, the refinery reportedly maintained operations by diversifying crude purchases across several origins, including African, American, and non-blocked Middle Eastern sources.

The strategic difference was that adaptation depended more heavily on external procurement. Emergency tenders, altered voyage patterns, working-capital needs, and possible increases in refined-product imports shifted part of the burden beyond the refinery. National crude-import weakness and inflation during the period are consistent with external cost pressure, but they cannot be attributed to refinery complexity alone. Exchange rates, administered prices, freight, insurance, and broader commodity-market conditions also mattered. The case therefore supports Proposition 2 only in a bounded sense: limited internal optionality increased reliance on market and national buffers but did not make adaptation impossible.

Pakistan: Operational Continuity Under Financial Constraint

Pakistan provides the clearest example of why output continuity should not be equated with low adaptation cost. Reported domestic refinery output increased year by year in March 2026, while fuel demand and import costs also rose. This combination indicates that the refining system continued to operate but did so within an economy facing severe foreign exchange and balance-of-payments pressure. Weekly oil-import costs were reported to have increased sharply during the disruption.

The case highlights a distinction between physical resilience and financial resilience. A refinery may continue processing while the country absorbs higher crude premiums, freight, insurance, product imports, and financing costs. In a lower-complexity system, fewer internal crude and product options can make this external burden more pronounced, but macroeconomic vulnerability is also decisive. Pakistan therefore supports the adaptation-cost-location argument more strongly than a simple complexity-performance claim.

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Table 1: Cross-case comparison of adaptation mechanisms and cost location

Case	Refining configuration	Primary adaptation mechanism	Principal cost location	Interpretive conclusion	Institutional mechanism mediating cost location
India – Jamnagar	Very high complexity; deep conversion	Internal product-slate and operating reconfiguration; broad crude flexibility	Predominantly firm-level operating, margin, and opportunity costs	Complexity expanded internal response options	Market-based pricing; limited state mediation of firm-level margin effects
South Korea	High-complexity national system	Diversified crude sourcing combined with strategic stocks and producer-linked storage	Shared between firms and public inventory institutions	Technical flexibility required complementary logistics	Producer-linked storage agreements and state-coordinated strategic release; costs shared by design
Vietnam – Nghi Son	More constrained crude relationship and operating envelope	Emergency crude-source diversification and greater reliance on external procurement	Procurement, trade, working-capital, and consumer-price channels	Adaptation remained possible but was more externalized	Managed but comparatively flexible import/FX regime; costs surfaced mainly through procurement and working capital before reaching consumers
Pakistan	Relatively simple and medium-conversion system under macroeconomic constraint	Domestic production continuity plus costly external procurement and financial buffering	Import bill, foreign exchange, public policy, and consumers	Physical continuity did not imply low economic cost	Administered fuel pricing and constrained foreign exchange reserves; costs surfaced through the import bill, FX reserves, and consumer prices

Cross-Case Synthesis: Two Adaptation Pathways

The cases reveal two broad pathways. The first is internal technical adaptation. It relies on conversion capacity, blending flexibility, product-yield choices, and the organizational ability to optimize the refinery under a changed crude slate. The second is external market and institutional adaptation. It relies on emergency tenders, storage drawdown, product imports, state coordination, foreign exchange, and the transfer of costs to customers or the public sector.

The precise channel through which an adaptation cost becomes visible is not determined by refinery complexity alone; it is mediated by specific institutional mechanisms. Administered pricing regimes can suppress the pass-through of higher crude and freight costs to consumers, which redirects the burden toward state fuel subsidies or state-owned refiner margins instead. Foreign-exchange reserve policy determines whether a higher import bill is absorbed through reserve drawdown, currency depreciation, or import compression, each of which has different distributional consequences. Consumer subsidy design determines whether cost pressure appears in retail fuel prices, in the fiscal deficit, or in inflation more broadly. These mechanisms explain why Pakistan's and Vietnam's adaptation costs, though both externalized relative to India and South Korea, surfaced through different channels: Pakistan's constrained reserve position pushed pressure toward the foreign-exchange and fiscal channel, while Vietnam's more flexible sourcing base pushed pressure toward procurement and working-capital costs before it reached consumers. It follows that refinery complexity primarily governs the range of internal technical choices available to a firm, while national fiscal capacity — reserve buffers, borrowing space, and subsidy affordability — governs whether external adaptation mechanisms such as emergency imports and consumer subsidies can be sustained. A lower-complexity system paired with strong fiscal capacity, and a lower-complexity system under fiscal constraint, are therefore expected to diverge in outcome even though both start from a similar internal option set; this is consistent with the contrast between South Korea's system-level buffering and Pakistan's constrained buffering observed in the cases.

These pathways are not mutually exclusive. South Korea combined both, and even Jamnagar depended on global logistics and markets. The analytical distinction concerns relative dependence. Higher complexity appears to increase the share of adaptation that can be managed within the operating system of the firm. Lower complexity increases reliance on external systems. This pattern supports both propositions while also showing that complexity is neither necessary nor sufficient for resilience. Scale, contracting, stocks, fiscal space, and governance remain important complementary conditions.

The cross-case result therefore differs from a simple "agile versus locked-in" dichotomy. All four systems demonstrated some capacity to adapt. What differed was the mechanism, the speed, and the location of the burden. This is strategically important because costs that remain inside the firm can be modelled, managed, disclosed, and compared against investment alternatives. Costs that migrate into trade balances, public inventories, inflation, or foreign-exchange stress are harder to attribute and may be recognized only after the shock.

Discussion

Reframing Asset Specificity

The findings suggest that the strategic consequence of asset specificity depends on the option structure embedded in the asset. A simple refinery may be less capital intensive but more dependent on a narrow crude and product configuration. A complex refinery may be more specialized in a capital sense yet more adaptable in an operational sense. This distinction extends TCE by showing that the same investment can simultaneously deepen commitment and broaden ex post choice.

The implication is not that firms should always maximize complexity. Conversion units are expensive, energy intensive, and vulnerable to changing environmental regulation and long-run demand. The strategic question is whether the option value of flexibility justifies the capital, operating, and transition risks. That question is where SMA can add value.

Adaptation- Cost Location as a Strategic Outcome

Most resilience studies classify outcomes in terms of continuity, recovery time, or output loss. Those measures can miss the transfer of cost across organizational boundaries. Pakistan's output continuity and Vietnam's sourcing diversification could be coded as resilience successes. Yet a broader accounting view reveals that continuity may have been purchased through higher import costs, inventory depletion, policy intervention, or consumer-price pressure.

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Adaptation-cost location therefore complements conventional resilience metrics. It asks not only whether the system continued operating, but who financed continuity, where the cost appeared, and whether decision makers could observe it in advance. This concept is relevant beyond refining. Asset-specific industries such as petrochemicals, LNG, power generation, and semiconductor manufacturing may also preserve output by shifting costs into suppliers, governments, or customers.

The Role of Strategic Management Accounting

The paper does not empirically demonstrate that SMA practices caused the observed responses. Its contribution is to show why a strategic accounting framework is needed. Firms currently disclose market-price, interest-rate, and currency sensitivities in considerable detail, but rarely disclose the operational sensitivity of their asset base to feedstock substitution. NCI alone is insufficient because two refineries with similar complexity can differ in crude assays, unit bottlenecks, hydrogen capacity, maintenance status, logistics, and contracts. Nevertheless, a complexity-adjusted risk framework can organize the relevant information.

A useful disclosure would combine: (1) refinery complexity and major conversion units; (2) dependence on a small number of crude grades or supply corridors; (3) feasible substitute-slate ranges; (4) expected changes in product yields and operating cost under specified shock scenarios; (5) inventory coverage; and (6) contractual or storage options available outside the disrupted route. Such a disclosure would convert engineering flexibility into strategically comparable information.

Strategic Implications

Complexity-Adjusted Supply-Risk Accounting

Refining and petrochemical firms should incorporate feedstock-switching scenarios into enterprise risk management and strategic investment appraisal. The goal is not to report a single resilience score, but to present a decision-useful range of outcomes. Scenario analysis should compare at least three states: normal supply, partial route disruption, and prolonged loss of the dominant crude source. For each state, management should estimate procurement premiums, freight and insurance, working capital, hydrogen and energy demand, product-yield changes, inventory usage, and the expected duration of feasible operations.

Table 2 illustrates how the disclosure items proposed in “The Role of Strategic Management Accounting” section can be structured as a complexity-adjusted supply-risk disclosure, mapping shock scenarios against the adaptation-cost-location channels identified in “Cross-Case Synthesis: Two Adaptation Pathways” section.

Table 2. Illustrative complexity-adjusted supply-risk disclosure

Scenario state	Expected internal (firm-level) response	Expected external (institutional) response	Primary adaptation-cost-location channel
Normal supply	Baseline crude slate and product yields; no scenario cost triggered	Routine strategic-stock rotation only	None (baseline)
Partial route disruption	Blend adjustment, unit severity changes within existing conversion capacity	Selective spot procurement; partial stock release	Firm operating cost and margin; limited public-inventory drawdown
Prolonged loss of dominant crude source	Full product-slate reconfiguration where conversion capacity allows; otherwise run-rate constraints	Emergency tenders, product imports, subsidy activation, FX reserve use	Distributed: firm margin (high-complexity systems) or trade account / FX / consumer prices (low-complexity systems)

This information can support capital decisions about hydrocracking, coking, desulfurization, blending, storage, and import terminals. It can also prevent firms from over-investing in physical complexity when contractual, logistical, or storage options provide a cheaper hedge. Complexity should be valued as one source of optionality within a portfolio of resilience investments.

Joint Stockpiling and Distributed Storage

For smaller or lower-complexity importing economies, immediate refinery upgrading may be financially unrealistic. Producer-linked storage and joint stockpiling can provide a lower-capital alternative. South Korea's arrangements illustrate how overseas producer stocks can function as an exercisable supply option during a chokepoint disruption. A generalized model would allow multiple producers to lease storage in an importing country in return for commercial benefits and clearly specified emergency-access rights.

Such arrangements are not costless and require transparent governance, quality compatibility, rotation rules, and credible release procedures. They also cannot substitute for conversion capacity when stored crude is incompatible with domestic refineries. The strategic value lies in combining geographically diversified stocks with a documented map of refinery compatibility.

Policy Implications

Governments should evaluate strategic petroleum reserves by quality and usability, not only by volume. A reserve measured in days of net imports may provide false comfort if the stored grades cannot be processed efficiently by domestic assets or if product inventories do not match likely shortages. Reserve policy should therefore be linked to refinery configuration, product-demand structure, and emergency logistics.

Public agencies should also collect and publish more granular data on refinery intake, product output, inventories, and crude origins. The absence of consistent open refinery-level data limits both policy evaluation and scholarly research. A post-crisis data initiative linking JODI, customs data, national statistics, and refinery disclosures would materially improve future analysis.

Conclusion

This study examined how refinery complexity influenced adaptation during the 2026 Gulf energy crisis. The evidence does not support a deterministic claim that low-complexity refineries failed while high-complexity refineries survived. All four cases found ways to sustain operations or domestic supply. The more defensible conclusion is that complexity influenced the mechanism and location of adaptation costs.

Highly complex systems had more options to reconfigure operations internally, although those options depended on scale, logistics, contracts, and public support. Lower-complexity systems relied more heavily on emergency sourcing, inventories, imports, and macroeconomic buffers. The resulting costs were therefore more likely to appear outside the refinery—in trade accounts, foreign-exchange pressure, public inventories, and consumer prices.

Theoretically, the study separates asset specificity from operational optionality. Refinery complexity does not make physical assets less specific; it can embed a wider response set within those specific assets. Managerially, the study introduces adaptation-cost location as an outcome that should be incorporated into strategic risk analysis. For accounting and disclosure, the implication is to move beyond static NCI reporting toward scenario-based, complexity-adjusted supply-risk information.

Future research should test these arguments with a refinery-month panel after final 2026 data become available, using consistent refinery-configuration measures, JODI throughput and output data, customs-based crude-origin measures, inventory releases, exchange rates, and subsidy controls. Interviews with refinery managers, accountants, traders, and public-stockpile agencies would also be required to establish whether SMA practices shaped decisions during the crisis. Until such evidence is available, the present findings should be treated as theory elaboration grounded in comparative case evidence rather than as a general causal estimate.

Declarations

Funding: No external funding was reported for this study.

Conflict of Interest: The authors declare no conflict of interest.

Data Availability: The data supporting the findings of this study are available from publicly accessible sources referenced in the manuscript. The authors confirm that all data required to reproduce the results are available without restriction from the original sources. All 2026 observations should be treated as provisional until final-year datasets are released.

Ethics Statement: The study uses documentary and aggregate secondary data and did not involve human participants.

Author Contribution: The authors are responsible for conceptualization, data collection, analysis, and writing.

Use of Generative AI: OpenAI ChatGPT (GPT-5.6 Thinking) was used to assist with language editing, manuscript organization and document formatting of author-prepared material. It was not used as a source of empirical evidence or to determine the study findings. The analytical data, statistical outputs,

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citations, interpretations and final text were reviewed and approved by the authors, who take full responsibility for the manuscript.

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