The Bioethics and Health Law Institute
The Iranian Association of Medical Law

Medical Law Journal
Scientific-Research
Journal homepage: http://ijmedicallaw.ir

Original Article

Pharmaceutical Supply Inefficiency in Developing Countries: A Study Framework Based on an Integrated AHP Model

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Article Information

Article History:

Received: 20 September 2026
Accepted: 06 October 2026
Available online: 21 October 2026

Keywords:

Pharmaceutical Supply Inefficiency
Developing Countries
Case Study Framework
Analytic Hierarchy Process
Access to Medicines
Insurance Coverage
Market Concentration
Pharmaceutical Supply Chain
Universal Health Coverage

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ABSTRACT

Inefficiencies in pharmaceutical supply in developing countries rarely arise from a single factor; rather, they reflect interactions among financial constraints, market structure, production capacity, import dependence, and regulatory conditions. Beyond the physical availability of medicines, these factors may affect affordability, quality, equitable patient access, and supply chain resilience. This study aimed to develop an integrated multicriteria framework for identifying and prioritizing the factors contributing to pharmaceutical supply inefficiencies in the health systems of developing countries. An expert-informed decision-making model was developed using the analytic hierarchy process (AHP). In this study, the term "case study framework" refers to a structured analytical model representing common conditions affecting pharmaceutical supply systems in developing countries, rather than an empirical assessment of the pharmaceutical system of a specific country. The hierarchical model comprised four main criteria - cost, quality, access, and availability of alternatives - and eight contributing factors: market concentration, insurance coverage, profitability, production capacity, import dependence, trade tariffs, information transparency, and access to raw materials. A panel of 15 experts with professional experience in pharmaceutical policymaking, pharmaceutical manufacturing and industrial management, supply chains, distribution networks, procurement, insurance, pharmaceutical economics, and pharmaceutical research participated in the pairwise comparison process. Eligibility required at least 10 years of relevant academic, managerial, operational, or policymaking experience. Expert judgments were collected through structured pairwise comparisons using Saaty's nine-point scale and aggregated using the geometric mean. Local and global priority weights were calculated using AHP software, version 9.28. A consistency ratio below 0.10 was considered acceptable. Sensitivity analysis was performed by varying the weights of the main criteria to assess the stability of factor rankings under different policy scenarios. In the optimized model, insurance coverage ranked first, with a global priority weight of (19.6), followed by market concentration or monopoly, with a weight of (18.7), and profitability, with a weight of (11.8). Insurance coverage had the highest priority under the cost criterion, whereas market concentration was the most influential factor under the quality criterion. In the access-focused scenario, the weights of insurance coverage (weight: 16) and market concentration (weight: 17.5) converged. These two factors remained among the top two priorities across all sensitivity analysis scenarios, indicating that the overall ranking pattern was relatively stable despite changes in criterion weights. The findings suggest that pharmaceutical supply inefficiencies in the health systems of developing countries cannot be explained solely by insufficient production capacity or the physical unavailability of medicines. Financial protection for patients and market structure were the most influential components of the proposed framework, although their relative importance varied across policy scenarios. Achieving sustainable access to medicines therefore requires coordinated interventions to strengthen insurance coverage, reduce excessive market concentration, diversify supply sources, support economically viable production, and improve supply chain transparency. Because the model relies on expert judgments and provides a general framework for developing countries, its findings should be interpreted in light of the composition of the expert panel and the institutional characteristics of each pharmaceutical system.

Please cite this article as:

Mir Mohammadmakki SF. Pharmaceutical Supply Inefficiency in Developing Countries: A Study Framework Based on an Integrated AHP Model. Medical Law Journal. 2026; Special Issue: e6.

https://doi.org/10.22037/bhl.v6i6.53515.

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Introduction

Continuous access to safe, effective, high-quality, and affordable medicines is a fundamental component of public health, universal health coverage, and public confidence in healthcare systems. Pharmaceutical supply is not merely a technical or logistical activity; it is a system-level process that connects pharmaceutical policymaking, market regulation, domestic production, imports, financing, insurance coverage, quality control, procurement, and distribution. Disruption in any of these interconnected components may lead to medicine shortages, price increases, restricted patient access, treatment interruptions, and expansion of the market for substandard or falsified products (1-4). Globalization has further increased the interdependence of pharmaceutical supply chains, meaning that disruptions in active pharmaceutical ingredient production, transportation, international trade, or the operations of a single major manufacturer may simultaneously affect several countries. Pharmaceutical supply efficiency is therefore directly connected to Sustainable Development Goal 3 and its emphasis on universal health coverage and access to safe, effective, quality-assured, and affordable essential medicines and vaccines. In this context, the contribution of the existing literature extends beyond documenting medicine shortages: it demonstrates that the continuity of pharmaceutical supply depends on the coordinated performance of financial, industrial, regulatory, and distribution systems. An increase in the number of registered medicines or nominal production capacity cannot be regarded as genuine access unless medicines are available to patients at the appropriate time and place, at an affordable price, and with assured quality (1, 5, 6).

Pharmaceutical supply challenges in developing countries are often structural, multidimensional, and context-dependent. High reliance on imported medicines and raw materials, exchange-rate volatility, limited domestic production capacity, inadequate insurance coverage, substantial out-of-pocket expenditure, informal markets, weak storage and distribution infrastructure, and constrained regulatory capacity collectively create a vulnerable supply environment. Under such conditions, even a relatively limited disruption in foreign-currency allocation, customs clearance, transportation, or procurement of active pharmaceutical ingredients may reduce production or generate widespread shortages (7-9). These factors should not be interpreted as isolated barriers because a change in one component may intensify weaknesses elsewhere. For example, currency shortages may restrict raw-material imports, reduce domestic production, increase prices, and ultimately limit patient access.

The coexistence of formal and informal sectors within pharmaceutical distribution systems adds another layer of complexity. In many underserved settings, private retail outlets and medicine vendors are the first point of contact for patients seeking treatment. Although these providers may improve geographical access, their operation outside formal regulatory networks can complicate product traceability, monitoring of storage conditions, and quality assurance. Shortages or high prices in the formal system may also push patients toward informal markets, thereby increasing their potential exposure to substandard or falsified products (10-12). Thus, policies that improve physical distribution without addressing affordability, regulation, and quality assurance may expand nominal access without ensuring safe and effective access.

Pharmaceutical supply inefficiency cannot therefore be defined solely as the physical unavailability of a product. A medicine may be present in the market but remain effectively inaccessible because of high prices, inadequate insurance coverage, unequal distribution, or the absence of an appropriate substitute (13, 14). Accordingly, pharmaceutical supply efficiency should be assessed across four interrelated dimensions: cost, quality, access, and availability of alternatives. Cost reflects patients' ability to pay and the financial burden imposed on the health system. Quality concerns compliance with established safety, efficacy, manufacturing, and procurement standards. Access refers to the timely and geographically appropriate availability of medicines. Availability of alternatives reflects the presence of generic products, an additional manufacturer, another import source, or a

substitute therapeutic pathway (13-17). Although these dimensions can be defined separately, they cannot be managed independently: an affordable medicine of uncertain quality does not represent effective access, just as a quality-assured medicine provides limited benefit when it is geographically unavailable or financially inaccessible.

These four dimensions are influenced by a range of structural and commercial factors. Market concentration may increase pricing power, weaken competition, reduce purchaser and patient choice, and make health systems dependent on a limited number of manufacturers, importers, or distributors. Insurance coverage affects patients' financial capacity, effective demand, reimbursement arrangements, and pharmaceutical purchasing mechanisms. Profitability determines whether producing or supplying a medicine remains commercially viable. Low profit margins for certain essential medicines may lead manufacturers to reduce production or withdraw from the market, while higher returns on other products may redirect resources toward more commercially attractive medicines (18-20). This creates an important policy tension: expanding insurance coverage may improve affordability and increase effective demand, but without adequate production incentives and procurement capacity, the resulting rise in demand may place additional pressure on an already constrained supply system.

Domestic production, imports, tariffs, and access to raw materials also interact in ways that may either strengthen or weaken pharmaceutical supply. Expanding domestic production can reduce dependence on imported finished medicines and improve resilience; however, production capacity alone cannot guarantee continuous supply without reliable access to active pharmaceutical ingredients, technology, equipment, foreign currency, skilled personnel, and adequate market demand (18, 21, 22). Imports can provide medicines whose domestic production is technically infeasible or economically unjustifiable, but they also expose pharmaceutical systems to exchange-rate fluctuations, transportation disruptions, trade restrictions, and customs delays. Inappropriately designed tariff policies may increase the costs of finished medicines, raw materials, or manufacturing equipment and may therefore produce conflicting effects on domestic production and patient access (19, 21, 23, 24). Domestic production and importation should therefore not be treated as mutually exclusive solutions. Their effectiveness depends on the wider financial, industrial, and regulatory conditions in which they operate.

Information transparency is another important component of pharmaceutical supply efficiency. Access to reliable information on inventory levels, consumption patterns, prices, orders, contracts, delivery times, and shortages enables more accurate demand forecasting and timely decision-making. Conversely, fragmented information across insurance organizations, regulatory authorities, manufacturers, importers, distributors, and healthcare facilities may lead to overprocurement of some medicines and simultaneous shortages of others. Insufficient transparency may also increase the risks of stockpiling, unequal distribution, conflicts of interest, and unaccountable decision-making (19, 25, 26). Effective monitoring must therefore extend beyond inventory records to include quality control, production and import performance, supplier reliability, delivery times, prices, market structure, insurance performance, and pharmaceutical traceability. Nevertheless, inadequate interinstitutional coordination, weak data integration, and the absence of standardized indicators continue to constrain pharmaceutical supply monitoring in many developing countries (27-30). The central challenge is therefore not merely a shortage of information, but the absence of an integrated approach through which different types of information can be interpreted and translated into policy priorities.

The complex relationships among cost, quality, access, production, imports, insurance coverage, market structure, and information transparency require a structured decision-making method. The Analytic Hierarchy Process (AHP) is a well-established multicriteria decision-making approach that decomposes a complex problem into hierarchical levels comprising an overall objective, evaluation criteria, and contributing factors. Through pairwise comparisons, it enables the relative importance of these elements to be

estimated systematically (31-33). A principal advantage of AHP is its capacity to combine quantitative evidence with structured expert judgment. In pharmaceutical supply systems, variables such as prices, inventory levels, delivery times, production capacity, and import shares may be measured quantitatively, whereas transparency, market power, substitutability, and regulatory effectiveness often require expert assessment. AHP enables these heterogeneous considerations to be evaluated within a common analytical structure, which is especially relevant in settings where systematic and integrated data are limited (34-36).

AHP can be applied to supplier evaluation, procurement strategy selection, comparisons between domestic production and importation, determination of strategic stock levels, prioritization of essential medicines, and assessment of insurance and tariff policies. Sensitivity analysis can further demonstrate how changes in the importance assigned to cost, quality, access, or availability of alternatives affect the ranking of pharmaceutical supply factors, allowing policymakers to examine alternative scenarios before implementing a decision (37-39). However, the available literature has largely examined individual dimensions of pharmaceutical supply or applied decision-making methods to specific operational choices. It provides limited guidance on how financial, industrial, commercial, and regulatory determinants should be weighed against one another when they operate simultaneously. Consequently, policymakers may be able to identify numerous barriers but still lack a transparent mechanism for determining which barriers deserve priority under different policy objectives.

The need for such a framework is particularly evident in developing-country settings. Increased production cannot be sustained without reliable access to raw materials; imports cannot be maintained without foreign currency and efficient customs procedures; price controls that disregard actual production costs may reduce the availability of low-profit medicines; and expansion of insurance coverage without corresponding reforms in procurement, production, and distribution may increase demand without generating adequate supply. A framework is therefore required that integrates cost, quality, access, and availability of alternatives with market concentration, insurance coverage, profitability, production capacity, imports, tariffs, transparency, and access to raw materials (40-42).

The specific gap addressed by this study is the absence of an integrated and transparent prioritization model capable of evaluating these interdependent determinants within a single decision structure. Existing research has established the importance of many individual supply barriers, but it has not adequately demonstrated their relative importance or how their rankings may change when policymakers place greater emphasis on cost, quality, access, or availability of alternatives. Accordingly, the present study aimed to develop and prioritize an expert-informed AHP framework for analysing pharmaceutical supply inefficiency under structural conditions commonly encountered in developing-country health systems. The proposed framework makes three contributions: it integrates financial, industrial, commercial, and regulatory determinants within one model; it estimates their relative priorities rather than treating all barriers as equally influential; and it uses sensitivity analysis to examine the stability of these priorities under alternative policy scenarios. The framework is intended to support the identification of dominant bottlenecks and the selection of coordinated policies for strengthening sustainable, equitable, and affordable access to quality-assured medicines. It should be interpreted as a general expert-informed decision-support framework that can be adapted to different national contexts, rather than as a nationally representative empirical evaluation of a single country.

Method

1. Study Design

This quantitative study used the analytic hierarchy process (AHP), a multicriteria decision-making method, to develop a framework for assessing pharmaceutical supply inefficiencies in developing countries and prioritizing their contributing factors. The

study was designed to integrate the economic, quality, production, trade, and access dimensions of pharmaceutical supply systems.

In this study, the term "case study framework" refers to a decision-making model based on expert judgments, developed to represent common structural conditions in pharmaceutical supply systems in developing countries. It does not refer to an empirical assessment of a specific country's pharmaceutical system or a direct comparison across countries. Accordingly, the findings should be interpreted as the outputs of a general analytical model that can be adapted to different national contexts, rather than as findings representative of a particular national pharmaceutical system.

Four main criteria - cost, quality, access, and availability of alternatives - and eight contributing factors - market concentration, insurance coverage, profitability, production capacity, import dependence, trade tariffs, information transparency, and access to raw materials - were identified through a targeted review of the literature on access to medicines, pharmaceutical economics, medicine shortages, domestic production, imports, market regulation, and supply chain management. The initial factors were assessed for their conceptual relevance to pharmaceutical supply inefficiency, frequency of occurrence in the literature, and suitability for evaluation through expert judgments before being incorporated into the final model. The preliminary framework was subsequently reviewed and endorsed through face-to-face discussions with experts.

The study was conducted in five main stages:

1. Developing a conceptual framework for pharmaceutical supply inefficiency through a targeted review of the relevant literature;

2. Designing a hierarchical model comprising the overall goal, four assessment criteria, and eight contributing factors;

3. Selecting eligible experts and collecting their professional judgments;

4. Conducting pairwise comparisons using Saaty's fundamental 1-9 scale, aggregating judgments using the geometric mean, and calculating local and global priority weights;

5. Assessing judgment consistency and model validity, evaluating model performance, and conducting sensitivity analyses under different scenarios.

The draft model was circulated among experts during the years 2023-24. Fifteen experts participated in this stage, with professional backgrounds in pharmaceutical policymaking, pharmaceutical manufacturing and industrial management, supply chains, distribution networks, procurement, insurance, pharmaceutical economics, and pharmaceutical research. Experts were selected through purposive sampling based on predefined eligibility criteria, including at least 10 years of relevant academic, managerial, operational, or policymaking experience.

Pairwise comparison data were analyzed using AHP software, version 9.28. The consistency index and consistency ratio were calculated to assess the logical consistency of the judgments, with a consistency ratio below 0.10 considered acceptable. When the consistency ratio of a matrix exceeded 0.10, further discussions were held to revise and improve the model structure and component weights. Following these revisions, the consistency ratio was recalculated, and only matrices meeting the specified consistency criterion were included in the final aggregation of judgments.

2. Development of the Conceptual Framework

The conceptual structure of the model was developed through a targeted review of the literature on access to medicines, supply chain management, pharmaceutical economics, medicine shortages, domestic production, imports, insurance coverage, and market regulation. The framework was designed to capture not only the technical aspects of pharmaceutical procurement and supply but also the financial, trade-related, and structural factors affecting medicine availability.

The final factors were selected according to four considerations: Their frequency and importance in the pharmaceutical supply literature, their

applicability across different medicine categories, their responsiveness to policy or managerial interventions, and their suitability for separate assessment through pairwise comparisons in the AHP model. Factors with substantial conceptual overlap were grouped into broader categories to avoid duplication and double counting. Market concentration, insurance coverage, profitability, production capacity, import dependence, trade tariffs, information transparency, and access to raw materials were therefore selected as the main factors. These factors represent the principal financial, market, production, trade, information, and input supply mechanisms discussed in the literature on pharmaceutical supply system performance (1, 13, 18, 19, 21).

Other relevant variables were not considered unimportant; instead, they were incorporated within the broader factors included in the hierarchy. Cold chain infrastructure was not included as a separate, universally applicable factor because its importance varies substantially across medicine categories and is primarily relevant to temperature-sensitive medicines and products. Nevertheless, when adapting the framework to a particular national pharmaceutical system, therapeutic area, or product category, cold chain infrastructure and similar factors can be added as context-specific subfactors.

In this study, pharmaceutical supply inefficiency was defined as a condition in which the pharmaceutical system is unable to provide patients with the medicines they need at an affordable cost, with assured quality, at the appropriate time and location, and with sufficient alternatives.

The four main criteria were operationally linked to patient-related outcomes. The cost criterion was associated with out-of-pocket expenditure, patients' financial capacity, treatment initiation, and the likelihood of treatment nonadherence due to financial barriers. The quality criterion was associated with patients' potential exposure to substandard or falsified medicines, treatment failure, and preventable safety risks. The access criterion addressed treatment delays, interruptions in treatment continuity, geographical inequalities, and patients' inability to obtain medicines when clinically needed. The availability of alternatives reflected the possibility of substituting a medicine, manufacturer, importer, or treatment pathway when the primary supply route was disrupted. Pharmaceutical supply inefficiency therefore occurs when weaknesses in one or more of these dimensions undermine the continuity, affordability, safety, or clinical effectiveness of pharmaceutical care, particularly in resource-constrained settings.

3. Hierarchical Structure of the Model

The study hierarchy comprised three main levels.

Level 1: Overall goal: Identifying and prioritizing the factors contributing to pharmaceutical supply inefficiencies in developing countries.

Level 2: Main criteria: Cost; Quality; Access; Availability of alternatives.

Level 3: Factors affecting pharmaceutical supply: Market concentration; Insurance coverage; Profitability; Production capacity; Imports; Trade tariffs; Information transparency; Access to raw materials.

Each of the eight factors was evaluated against all four main criteria. Assessment across criteria was necessary because a single structural factor may affect several patient-related outcomes through different pathways. For example, market concentration may increase prices, reduce competition, restrict choice, and limit access to alternative manufacturers or importers. Insurance coverage may reduce patients' out-of-pocket expenditure and improve financial access; however, the increase in effective demand following insurance expansion may place additional pressure on production and procurement systems.

Similarly, import dependence may affect cost through exposure to exchange rate fluctuations, access through transport or customs clearance delays, quality through differences in regulatory oversight, and the availability of alternatives through reliance on a limited number of foreign suppliers. The proposed hierarchy therefore links upstream structural factors to downstream outcomes relating to affordability, quality, supply continuity, and patient access.

4. Expert Selection and Data Collection

The data required for pairwise comparisons were collected using a structured questionnaire completed by experts in pharmaceuticals and supply chain management. Experts were selected through purposive, criterion-based sampling to ensure the participation of individuals with relevant specialist knowledge and practical experience across different parts of the pharmaceutical supply system.

The eligibility criteria were:

- At least 10 years of relevant academic, operational, or managerial experience.

- Professional experience in pharmaceutical manufacturing, imports, distribution, or policymaking.

- Familiarity with insurance systems, market regulation, or pharmaceutical supply chains.

- Familiarity with the challenges affecting pharmaceutical systems in developing countries.

- Willingness to participate in the pairwise comparison process on an informed basis.

Eligible participants included health policymakers, pharmaceutical company managers, supply chain specialists, pharmacists, insurance managers, procurement officers, and faculty members or researchers in relevant fields.

Experts were classified according to their primary professional role to assess stakeholder representation and potential imbalances in the composition of the panel. Where an expert had experience in more than one field, classification was based on their primary professional affiliation to avoid duplicate counting.

If consistent with the actual study procedures: representation from different professional groups was considered during expert selection to reduce the likelihood that the perspectives of a single group would dominate the final priorities.

5. Data Collection Instrument

The pairwise comparison questionnaire was developed according to the hierarchical structure of the AHP model. Experts were asked to compare the relative importance of each pair of criteria or factors in relation to the overall study goal. Saaty's nine-point scale was used to express the intensity of preference:

1: Equal importance.

3: Moderate importance of one element over another.

5: Strong importance.

7: Very strong importance.

9: Extreme importance.

2, 4, 6, and 8: Intermediate values.

6. Implementation of the Analytic Hierarchy Process

The AHP model was implemented through the following steps:

1. Defining the overall goal and organizing the criteria and contributing factors;

2. Constructing the pairwise comparison matrices;

3. Entering expert judgments into AHP software, version 9.28;

4. Assessing the consistency of each expert's pairwise comparison matrices before aggregating the judgments;

5. Returning matrices with unacceptable consistency ratios to the relevant experts for reassessment;

6. Aggregating the accepted individual judgments using the geometric mean;

7. Calculating the local priority weights of the criteria and factors;

8. Calculating the global priority weights;

9. Determining the final ranking of the factors contributing to pharmaceutical supply inefficiency;

10. Calculating the consistency index and consistency ratio of the aggregated matrices;

11. Generating performance plots, ranking plots, and static model outputs;

12. Conducting dynamic scenario assessments and sensitivity analyses.

All calculations, including judgment aggregation, estimation of local and global priority weights,

consistency assessment, generation of performance plots, and sensitivity analysis, were performed using AHP software, version 9.28.

One of the main advantages of this method is its ability to evaluate different decision-making conditions. In addition to providing baseline results, the model can show how factor priorities change when greater importance is assigned to a particular criterion, such as cost or access. This capability allows pharmaceutical system managers and decision-makers to assess the potential implications of different policy scenarios before implementation.

7. Assessment of Judgment Consistency

The Consistency Index (CI) and Consistency Ratio (CR) were calculated to evaluate the logical coherence of the expert judgments. The Consistency Ratio was calculated as follows:

$$C = \frac{C}{R}$$

Where C represents the Consistency Ratio, C represents the Consistency Index, and R represents the Random Index.

The Consistency Index was calculated using the following equation:

$$C = \frac{\lambda_m - n}{n - 1}$$

Where λ_m is the principal eigenvalue of the pairwise-comparison matrix and $n$is the number of elements being compared.

8. Sensitivity Analysis

Sensitivity analysis was conducted to assess the robustness and stability of the findings. The weights assigned to the four criteria - cost, quality, access, and availability of alternatives - were systematically varied, and the effects of these changes on the global weights and rankings of the eight factors were examined.

In the baseline model, the weights of price, quality, access, and availability of alternatives were 32.2%, 52%, 11.4%, and 4.3%, respectively. When the weight of one criterion was changed, the weights of the remaining three criteria were adjusted proportionally and renormalized so that the total criterion weight remained equal to one in each scenario.

In all sensitivity analysis scenarios - cost-focused, quality-focused, access-focused, and alternatives-focused - the weight of the relevant criterion was increased from its baseline value to the maximum setting.

The global weights of the eight factors were recalculated in each scenario and compared with the baseline results. Model performance was assessed across the predefined conditions and scenarios by examining changes in global weights, shifts in factor rankings, and the presence or absence of rank reversals among the highest-priority factors. The model allowed different scenarios to be projected, and changes in each input component were clearly observable in the dynamic analysis when any of the top-level criteria were varied. Accordingly, the model was considered useful for evaluating different conditions and anticipating future situations under changes in its components, with the potential to help prevent unforeseen adverse events and associated losses.

The sensitivity analysis had the following objectives:

- To determine the stability of factor rankings.

- To identify the criteria with the greatest influence on the final results.

- To examine model behavior under scenarios emphasizing cost, quality, access, or availability of alternatives.

- To assess how increasing the importance of alternatives affects market structure.

- To identify factors that may become major bottlenecks during crises.

9. Data Analysis

Data were analyzed using specialized AHP multicriteria decision analysis software, version 9.28. Local and global priority weights were calculated for the criteria and factors, and their final rankings were determined. The findings were presented using performance plots, ranking plots, and sensitivity analysis outputs.

Because AHP relies on structured expert judgments and pairwise comparisons, parametric

inferential tests were not used to determine the weights. The validity and robustness of the findings were assessed with reference to judgment consistency ratios, agreement among experts, variation in individual weights, ranking stability in sensitivity analyses, and the logical correspondence between the results and the structure of the decision problem.

Individual expert rankings were unavailable; therefore, an independent measure of agreement among experts could not be calculated. This was acknowledged as a study limitation, and the stability of the results was assessed using the consistency ratio of the aggregated matrix and the scenario-based sensitivity analyses.

Results and Discussion

1. Assessment of the Main Criteria and Factors

In the AHP analysis, eight factors - market monopoly, insurance coverage, profitability, production capacity, import dependence, trade tariffs, transparency, and access to raw materials - were evaluated against four main criteria: Cost, quality, access, and availability of alternatives. Figure 1 presents the relative performance of these factors under each criterion.

Under the cost criterion, insurance coverage had the highest relative importance. This finding suggests that patients' ability to obtain medicines depends not only on nominal medicine prices but also on the extent of insurance protection, reimbursement arrangements, and insurance-based purchasing mechanisms, which play a decisive role in financial access. Under the quality criterion, market monopoly had the highest relative importance, potentially reflecting vulnerabilities associated with reliance on a limited number of manufacturers or importers.

Differences among factors were less pronounced under the access criterion, suggesting that access to medicines is shaped by several interconnected factors rather than a single dominant factor. Insurance coverage and market monopoly also had greater importance under the availability-of-alternatives criterion. An alternative medicine does not necessarily represent a viable choice if patients cannot afford it or if barriers to market entry prevent new suppliers from entering the market.

Overall, Figure 1 shows that the influence of each factor depends on the policy dimension being assessed. Financial protection is particularly important for patient affordability, whereas market structure is more prominent in relation to quality. Access and the effective availability of alternatives are influenced by a broader range of financial, production, import, and supply-related factors. Figure 1 should therefore be interpreted as a representation of criterion-specific priorities.

Figure 1: Hierarchical Structure and Relative Performance of Factors Contributing to Pharmaceutical Supply Inefficiency According to the Criteria of Cost, Quality, Access, and Availability of Alternatives

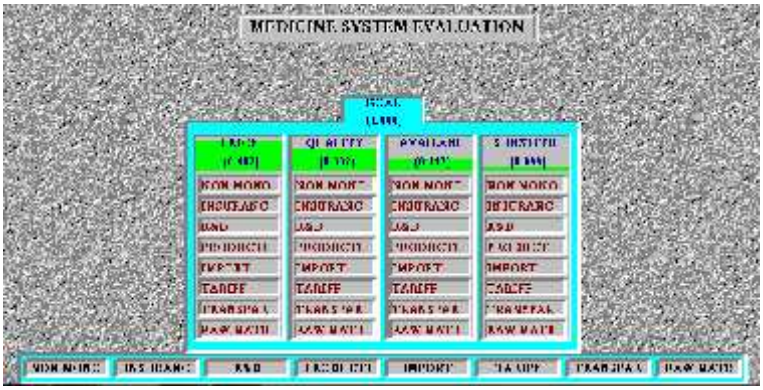


Figure 1 also illustrates the model's three-level structure. The first level represents the overall study objective: identifying and prioritizing the factors contributing to pharmaceutical supply inefficiency. The second level comprises four criteria - cost, quality, access, and availability of alternatives - while the third level includes the eight contributing factors.

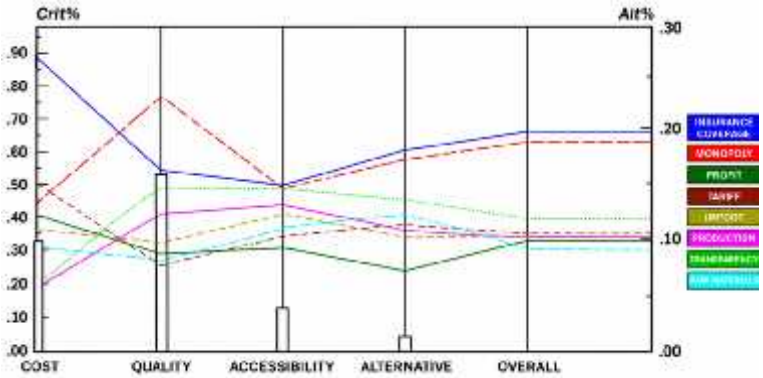
This structure indicates that pharmaceutical supply inefficiency is a multidimensional issue. Market monopoly may affect prices, quality, access, and the ability to use alternative suppliers. Insurance coverage may also influence patients' out-of-pocket expenditure, effective demand, medicine selection, and their ability to use alternative options.

Similarly, production capacity, imports, tariffs, transparency, and access to raw materials may operate simultaneously through different pathways. A lower ranking under a particular criterion should not be interpreted as evidence that these factors are unimportant. Rather, their effects may be more indirect, context-dependent, or distributed across several components of the model.

2. Baseline Scenario and Overall Priorities

Figure 2 presents the baseline configuration of the AHP model, which serves as the reference point for comparison with subsequent sensitivity analyses. In the baseline scenario, insurance coverage ranked first, with a global priority weight of 19.6%, followed by market monopoly at 18.7% and profitability at 11.8%. Trade tariffs, import dependence, production capacity, transparency, and access to raw materials occupied the subsequent positions, respectively.

Figure 2: Optimized Model Configuration and Final Ranking of Factors Contributing to Pharmaceutical Supply Inefficiency



The highest ranking of insurance coverage suggests that the physical availability of medicines alone does not guarantee effective access. Even when medicines are available on the market, inadequate financial protection may prevent patients from obtaining them. The second-place ranking of market monopoly highlights the risks associated with concentrating production, imports, or distribution among a limited number of suppliers. The third-place ranking of profitability suggests that continued production and distribution, particularly of essential and inexpensive medicines, depend on adequate economic incentives.

The priorities derived from AHP should not be interpreted as automatically prescribing a particular policy intervention. Rather, they indicate the relative order of policy attention to the identified constraints. Accordingly, the baseline findings support an initial focus on financial protection for patients and reform of market structure. Interventions addressing production sustainability, imports, tariffs, transparency, and the security of raw material supply should be considered complementary components of a coordinated strategy.

The overall ranking of factors in the baseline scenario was as follows:

1. Insurance coverage;
2. Market monopoly;
3. Profitability;
4. Trade tariffs;
5. Import dependence;
6. Production capacity;
7. Transparency;
8. Access to raw materials.

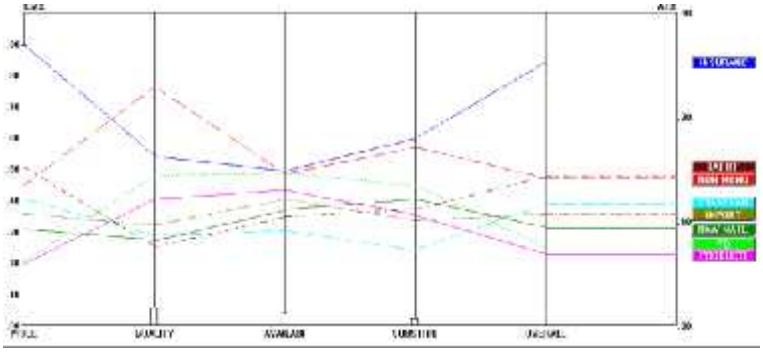
Differences among the middle-ranked factors were relatively small; therefore, minor changes in criterion weights may alter their order. By contrast, insurance coverage and market monopoly showed a more pronounced separation in priority from the lower-ranked factors.

The lower baseline rankings of transparency, production capacity, import dependence, and access to raw materials should be interpreted cautiously. Their effects may operate through higher-ranked factors, or they may become more important in particular national contexts or during crises. For example, access to raw materials may receive a lower overall weight in a balanced model but become critical when production depends on a single foreign source. Rankings therefore represent relative priorities within the model and should not be taken to mean that a factor is unimportant or can be omitted.

3. Scenario with Maximum Weight Assigned to Cost

The findings in Figure 3 indicate that when cost is prioritized, insurance protection and tariff policies become the most important considerations in decision-making.

Figure 3: Sensitivity Analysis Following an Increase in the Weight of the Cost Criterion



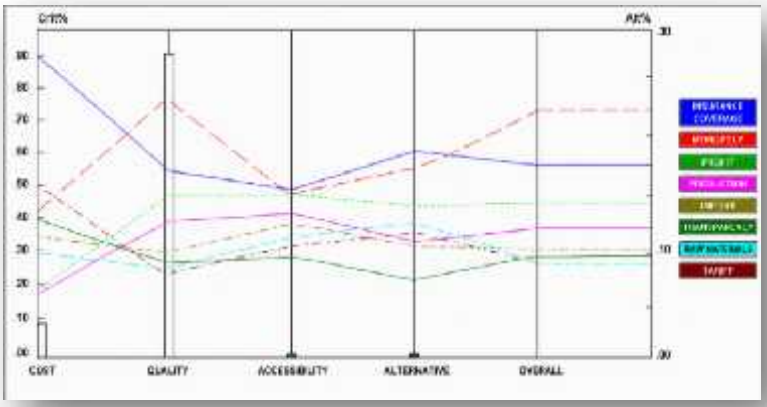
The ranking of market monopoly also highlights the importance of market competition when assessing factors associated with medicine prices and pharmaceutical supply costs.

From a policy perspective, this scenario emphasizes strengthening insurance protection, reviewing tariffs, and increasing competition to improve affordability and access to medicines.

4. Scenario with Maximum Weight Assigned to Quality

In the quality-focused scenario presented in Figure 4, the weight assigned to the quality criterion increased from 52% in the baseline model to the maximum setting of 90%. Following this change, market monopoly moved from second to first place, while insurance coverage ranked second. Profitability retained its third-place ranking, and the relative ranking of production capacity improved.

Figure 4: Sensitivity Analysis Following an Increase in the Weight of the Quality Criterion



The reversal of the two highest-ranked factors indicates that market concentration becomes more important when quality is the primary policy objective. Reliance on a limited number of manufacturers or importers may reduce opportunities to compare products and suppliers, weaken quality-based competition, and amplify the consequences of quality failures involving a dominant supplier.

In developing countries, this relationship may be intensified by weak regulatory enforcement, limited purchaser choice, and market conditions in which patients or healthcare facilities cannot readily switch suppliers. The rise of market monopoly to first place reflects both the direct consequences of supply concentration and the reduced ability of purchasers and regulatory authorities to use competition as a means of improving quality.

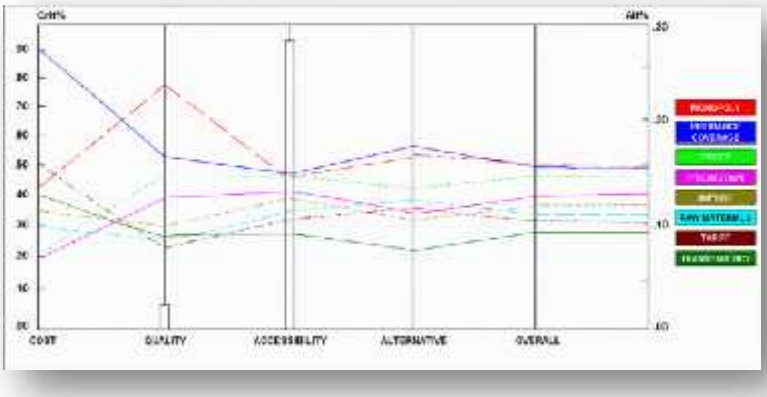
Insurance coverage remained a high priority because insurers can influence the quality of medicines used by patients through formulary design, supplier selection, reimbursement conditions, and requirements for compliance with quality standards. Profitability also retained its importance because investment in technology, quality control, reliable raw materials, and compliance with good manufacturing practices requires economically viable and sustainable production.

The rank reversal between market monopoly and insurance coverage does not indicate a statistically significant difference; rather, it reflects a change in decision-making priorities following an adjustment to the criterion weight. From a policy perspective, this scenario assigns greater priority to supplier diversification, quality-based procurement, oversight of dominant suppliers, and incentives for production that complies with established standards.

5. Access-Focused Scenario

As shown in Figure 5, increasing the weight of the access criterion narrowed the priority gap between insurance coverage and market monopoly, bringing the two factors to nearly equal levels of priority. At the same time, the roles of profitability, production capacity, import dependence, and access to raw materials became more apparent within the overall model.

Figure 5: Sensitivity Analysis Following an Increase in the Weight of the Access Criterion



This pattern underscores the financial and physical dimensions of access to medicines. Adequate insurance coverage cannot ensure access when medicines are unavailable, while physical availability does not guarantee effective access when patients cannot afford them.

The convergence of the ranking lines is more important than the small apparent difference between the two highest-ranked factors. This convergence indicates that neither financial protection nor market structure alone can overcome barriers to access.

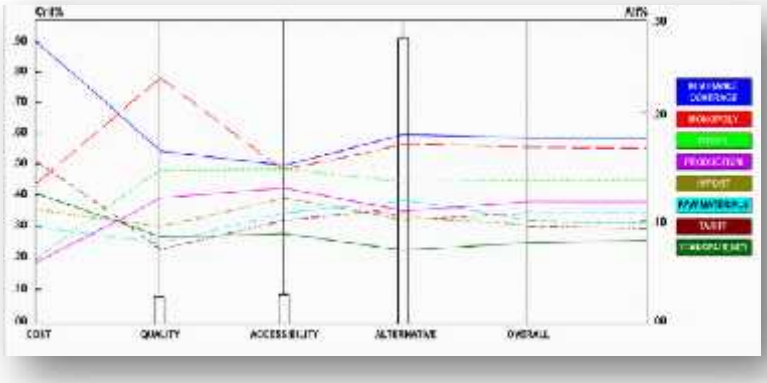
The access-focused scenario also highlights several common bottlenecks in pharmaceutical systems in developing countries. Import dependence may cause delays when foreign currency is unavailable, transport is disrupted, or customs clearance procedures are prolonged. Domestic production may shorten supply lead times, but it may not fully meet demand when raw materials are scarce, production capacity is limited, or economic conditions are unsustainable.

Accordingly, an access-focused strategy should begin by addressing financial and physical barriers simultaneously, then target the principal bottleneck causing the disruption. When affordability is the main barrier, reforms to insurance coverage and reimbursement should take priority. When medicines are physically unavailable, customs clearance, foreign currency allocation, production continuity, and raw material supply should become the immediate focus of intervention.

6. Scenario Focused on the Availability of Alternatives

As shown in Figure 6, increasing the importance of the availability of alternatives left insurance coverage in first place and market monopoly in second, although the priority gap between them narrowed. Profitability retained its third-place ranking, while access to raw materials gained relative importance.

Figure 6: Sensitivity Analysis Following an Increase in the Weight of the Availability-of-Alternatives Criterion



An alternative medicine or supplier has limited practical value if the product is not covered by insurance, is unaffordable for patients, or cannot enter a concentrated market. Market monopoly is therefore directly related to the number of manufacturers, importers, generic medicines, and secondary supply routes. Profitability also determines whether alternative suppliers have sufficient incentives to enter and remain in the market.

The increased importance of access to raw materials indicates that diversification should extend beyond finished products. Even the presence of multiple manufacturers does not eliminate vulnerability if they all depend on a single source of active pharmaceutical ingredients or excipients.

This scenario identifies three complementary forms of substitution: alternative medicines, alternative suppliers, and alternative supply routes. Effective resilience requires all three to be financially accessible to patients and operationally available.

7. Summary of the Sensitivity Analyses

The sensitivity analyses indicated that the model was relatively stable, as insurance coverage and market monopoly remained among the two highest priorities across all scenarios evaluated. Their order nevertheless varied with the policy objective. When greater importance was assigned to quality, market monopoly became the dominant factor; when access was emphasized, the priorities of the two factors converged; and when the availability of alternatives was given greater importance, insurance coverage retained its first-place ranking.

As discussed above and summarized in Table 1, market concentration and insurance coverage had nearly equal priorities in the access-focused scenario.

Table 1: Summary of Changes in the Rankings of Factors Contributing to Pharmaceutical Supply Inefficiency across AHP Sensitivity Analysis Scenarios

Model Scenario	Highest-Priority Factor	Second-Priority Factor	Main Change from Baseline
Baseline (Figure 2)	Insurance coverage	Market concentration	Reference ranking and balanced model configuration
Cost-based scenario; price weight of 90% (Figure 3)	Insurance coverage	Tariff	Insurance coverage remains first; tariff moves to second, and market concentration ranks third
Quality-based scenario (Figure 4)	Market concentration	Insurance coverage	The two leading factors exchange ranks, and production capacity gains importance
Access-based scenario (Figure 5)	Market concentration and insurance coverage, with nearly equal priorities	Profitability	Smaller differences between factor priorities and a more multidimensional pattern
Availability-of-alternatives scenario (Figure 6)	Insurance coverage	Market concentration	The two main factors remain prominent, and access to raw materials gains importance

Their precise order should therefore be interpreted using the numerical AHP results rather than the small visual differences in Figure 5. To avoid repeating the numerical information reported in the descriptions of Figures 2-6, the table summarizes only the principal ranking changes across the sensitivity analysis scenarios.

The scenarios provide a basis for determining the sequence of interventions. The baseline model prioritizes financial protection and market structure reform. A quality-focused strategy directs initial attention to competition, supplier oversight, and compliance with manufacturing standards. An access-focused strategy requires simultaneous attention to affordability and physical supply bottlenecks. A strategy emphasizing resilience and alternatives places greater importance on alternative products, secondary suppliers, multiple import routes, and diversified sources of raw materials.

8. Integrated Discussion of the Findings

The findings indicate that pharmaceutical supply inefficiency arises from interactions among insurance coverage, market monopoly, profitability, production capacity, import dependence, tariff policies, transparency, and access to raw materials. The relative influence of these factors is likely to vary according to each country's economic structure, industrial capacity, insurance system, and regulatory environment.

The prominence of insurance coverage under the cost criterion indicates that medicine prices alone do not determine patients' ability to receive treatment. However, expanding insurance coverage without improving procurement, demand forecasting, and stock availability may increase demand without a corresponding increase in supply.

The prominence of market monopoly under the quality and availability-of-alternatives criteria highlights the importance of market structure. Reliance on a single manufacturer, importer, or supply route increases the system's vulnerability to supplier failure. Although sourcing from a single supplier may reduce prices in some circumstances, it can weaken long-term flexibility and resilience.

The convergence of factor priorities under the access criterion underscores the multifactorial nature of access. Medicine requirements must be forecast, and medicines must be financed, manufactured or imported, cleared through customs, stored, distributed, and ultimately dispensed to patients. A disruption at any stage can prevent patients from receiving treatment.

Pharmaceutical policies may also have unintended consequences. Price controls that do not account for actual supply costs may encourage manufacturers to discontinue low-margin medicines. Protective tariffs may increase the cost of raw materials and manufacturing equipment. Centralized purchasing from a single supplier may strengthen purchasing power while increasing the risk of shortages resulting from that supplier's failure.

These findings indicate that policy recommendations should not be interpreted merely as a general list of desirable measures. Each recommendation corresponds to an AHP priority or scenario. Financial protection reforms address the high priority assigned to insurance coverage; competition policies and supplier diversification address market monopoly; production incentives relate to profitability and production capacity; and diversification of imports and raw material sources addresses factors that become more prominent in the access and resilience scenarios.

9. Comparison with Previous Studies

The present findings complement previous research on pharmaceutical supply chain resilience, coordination, procurement, distribution, medicine shortages, affordability, and universal health coverage.

These studies are not methodologically equivalent to the present AHP analysis. Empirical field studies demonstrate how a particular intervention or constraint operates in a specific setting, whereas the present model estimates the relative priorities of several interconnected factors. The comparison therefore provides thematic and contextual validation rather than direct methodological replication.

Ganguly and Kumar (43) used fuzzy AHP and the judgments of 23 experts to prioritize pharmaceutical supply chain resilience strategies in India, identifying agility, visibility, and collaboration as the leading strategies. Their emphasis on visibility is consistent with the inclusion of transparency in the present model. Their study, however, focused on organizational resilience, whereas the present framework also encompasses financing, market structure, profitability, imports, tariffs, and patient access.

The lower baseline ranking of transparency in the present model does not contradict the findings of Ganguly and Kumar; rather, it reflects differences in the decision objective. Transparency may be fundamental to organizational resilience but receive a lower global weight when assessed alongside insurance coverage and market structure at the health system level.

Mehralian et al. (44) used AHP to prioritize criteria and subcriteria influencing coordination among pharmaceutical supply chain members. Their findings support the view that supply chain performance emerges from interactions among multiple actors and processes. The present study extends this perspective by assessing supply performance against cost, quality, access, and availability of alternatives.

Thus, the coordination study explains how supply chain members can work together, whereas the present model identifies the system-level constraints that warrant greater policy attention.

In a cluster-randomized study involving 439 health facilities in Zambia, Vledder et al. (45) showed that reforms to distribution structures and information flows reduced the frequency and duration of medicine shortages. Their findings support the importance of distribution and information systems for physical access. The present framework, however, defines efficient supply more broadly by also considering affordability, quality, and availability of alternatives.

The two approaches are complementary: the field study provides causal evidence for a specific distribution intervention, whereas the AHP model positions distribution-related considerations within a broader set of policy priorities.

Modisakeng et al. (46) identified poor supplier performance, payment delays, inadequate contract management, insufficient communication, lengthy procurement processes, and shortages of active pharmaceutical ingredients in South African public hospitals. These findings support the importance of supplier reliability, transparency, procurement, and access to raw materials. Their study did not directly measure market concentration, however; its findings should therefore be interpreted as evidence of vulnerability associated with limited supply sources rather than direct evidence of market monopoly.

Furthermore, the public hospital procurement environment in South Africa, a middle-income country, differs from pharmaceutical systems in low-income countries or those heavily dependent on imports. In these settings, foreign currency shortages, customs delays, and reliance on foreign sources of raw materials may be more important. These contextual differences reinforce the need to adapt the proposed model to individual countries.

Seidman and Atun (5) found that procurement and supply chain reforms in low- and middle-income countries often reduce costs and improve product availability. They also emphasized that no single intervention is transferable to every setting. This finding supports the scenario-based nature of the present model. Centralized purchasing may reduce costs, but excessive reliance on a single supplier can increase vulnerability.

The present framework therefore explicitly captures the trade-off between procurement efficiency and the need to diversify supply sources.

Acosta et al. (47) described medicine shortages as a multifactorial phenomenon influenced by production, economic, trade, and regulatory problems, changes in demand, and weaknesses in information systems. This finding is consistent with the multidimensional structure of the present model. Their review, however, did not establish comparable priorities for these factors.

The present AHP framework addresses this limitation by translating structured expert judgments into criterion-specific priorities and global weights and evaluating them across different scenarios.

Wirtz et al. (1) emphasized that access to essential medicines depends on affordability, sustainable financing, assured quality, procurement, distribution, and appropriate use. This perspective provides a conceptual foundation for the four main criteria in the present study. The high priority assigned to insurance coverage aligns with their emphasis on financial protection, while the prominence of market monopoly adds a more explicit market structure dimension to the framework.

Accordingly, the principal gap addressed by this study is not the identification of previously unrecognized pharmaceutical supply problems, since earlier studies have documented many of these challenges. Its main contribution is the integration and relative prioritization of financial, market, production, trade, and information factors within a decision-making framework that responds to different policy scenarios.

10. Methodological Considerations and Limitations

The findings should be interpreted in light of several limitations. First, AHP weights are derived from structured expert judgments and therefore remain susceptible to subjectivity, professional interests, and biases arising from the composition of stakeholder groups.

The proposed framework represents common conditions in pharmaceutical systems in developing countries rather than an empirical assessment representative of a specific country. Differences in income levels, industrial capacity, regulatory enforcement, procurement structures, insurance coverage, and import dependence limit the uniform generalizability of the findings.

Finally, sensitivity analysis examines the model’s response to changes in criterion weights. Future studies should validate the framework using larger and more diverse expert panels, country-specific empirical indicators, measures of agreement among experts, and longitudinal data on shortages, prices, procurement, and patient access.

11. Synthesis and Policy Implications

The findings indicate that pharmaceutical supply system reform should combine financial protection for patients with market structure reform and greater supply chain resilience. Insurance reform without sufficient supply capacity may increase demand without improving availability, while expanding supply without financial protection may leave medicines beyond patients' reach.

The model's policy value lies in determining the sequence of interventions rather than simply listing possible measures. Reforming financial protection and reimbursement systems is the initial priority in the baseline scenario. When quality is the primary objective, competition policy, supplier oversight, and compliance with manufacturing standards take precedence. In the access-focused scenario, measures to improve affordability should accompany interventions addressing customs clearance, foreign currency allocation, production continuity, and distribution. When resilience and alternatives are prioritized, secondary suppliers, alternative products, multiple import routes, and diversified sources of raw materials become more important.

This sequence should be adjusted to the dominant bottleneck in each pharmaceutical system. A uniform policy package is unlikely to suit countries with different financing systems, production capacities, regulatory environments, and levels of import dependence.

Conclusion

Pharmaceutical supply inefficiency arises from interactions among financial protection, market structure, the economic viability of production, production capacity, trade conditions, information transparency, and the security of raw material supply. The integrated AHP framework provides a structured method for identifying the factors that warrant greater attention under different policy objectives.

Insurance coverage and market monopoly retained central positions across the scenarios evaluated, although their relative importance changed as greater emphasis was placed on quality, access, or availability of alternatives.

This finding indicates that sustainable pharmaceutical supply requires simultaneous attention to patient affordability and the resilience of market structures and cannot be achieved solely by increasing production or imports.

The model should be used as a decision-support tool rather than a mechanism that automatically prescribes a particular policy. Its priorities can guide the sequence of interventions.

Because the framework relies on expert judgments and a general representation of conditions in developing countries, its results are sensitive to panel composition, the design of the hierarchy, and the national context. Nevertheless, by making policy trade-offs explicit and examining priority stability across scenarios, the framework provides a practical basis for more transparent planning tailored to local conditions. Its broader contribution is to connect universal health coverage with the financial, competitive, and industrial conditions needed to ensure that quality medicines are not only manufactured or imported but also remain consistently and equitably accessible to patients.

Funding

The author states that no financial support was received for the research, authorship or publication of this article.

Acknowledgements

None declared.

Authorship

All stages of the research - including the conception and design of the study, data collection and analysis, manuscript writing and revisions - were carried out exclusively by the author, Seyed Fathollah Mir Mohammadmakki.

Conflict of Interest Statement

The author declares that there is no conflict of interest regarding the conduct of this research.

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