

Analysis of the Societal Benefits Derived from Reducing Pharmaceutical Prices based on System Dynamics

Yuzhu Zhang, Yunxia Cheng, Yiting Guo, Rong Hu, Qiang He *

Tianjin University of Traditional Chinese Medicine, China

*Corresponding author

Abstract. The steep prices of pharmaceuticals have long been a significant concern in the healthcare domain, directly impacting patients' financial burdens, government healthcare expenditures, and the operational dynamics of the pharmaceutical market. This study aims to analyze the societal ramifications of lowering drug prices through the lens of system dynamics methodology. Employing a system dynamics model, this study evaluates the effects of drug price adjustments on patients, governments, and the broader society, while also investigating the outcomes across various policy and market scenarios. Findings indicate that reducing drug prices within a certain range can alleviate patients' financial burdens, enhance the accessibility and equity of healthcare services, and decrease government healthcare expenditures, thereby bolstering healthcare coverage. Additionally, the decline in drug prices contributes to narrowing the wealth gap and fostering social equity and stability. The outcomes of this study offer valuable insights for government policy-making and market management in the pharmaceutical sector, facilitating the advancement of a robust pharmaceutical market and societal progress.

Keywords: Pharmaceutical Price; Social Benefits; System Dynamics.

1. Introduction

The exorbitant prices of pharmaceuticals have long been a pivotal issue within the healthcare system, impacting patients' healthcare cost burden, insurance expenditures, pharmaceutical companies' profitability, as well as the accessibility and equity of healthcare services. Various stakeholders including governments, pharmaceutical companies, patients, and their families have different interests and concerns regarding drug pricing, making it a focal point of governmental decision-making and market mechanisms.

This paper aims to address the issue from multiple dimensions including governmental policies, pharmaceutical company behaviors, and patient responses. We will construct a system dynamics model to elucidate the interactions and feedback mechanisms among various variables during the process of drug price adjustments. By simulating different policy measures and market scenarios, we will explore the impacts of reducing drug prices on patients' financial burden and health status, governmental negotiations, social equity, and assess and forecast potential policy outcomes and risks. It is hoped that through the approach of system dynamics, a more comprehensive understanding of the complex impact mechanisms of drug price adjustments can be achieved, providing governments with more scientific and reliable bases for decision-making, while also offering beneficial references and suggestions for the healthy development of the pharmaceutical market and the protection of patients' interests.

2. Literature Review

Several studies have explored the benefits of drug price reduction in various contexts. Goldman et al. (2004) [1] conducted a retrospective study to determine how changes in cost sharing affect the use of drugs among the privately insured and the chronically ill. Lakdawalla et al. (2007)[2] examined the welfare effects of public drug insurance. Zhou et al. (2015)[3] assessed the financial impact of the Zero-markup Policy for Essential Drugs (ZPED) on patients in county hospitals in rural China,



finding that the policy reduced medical expenses for patients. Karnon et al. (2015)[4] discussed the effects of non-maintenance of equivalent prices when pharmaceutical comparators come off-patent and are subject to price reductions. Kazi et al. (2020)[5] estimated the cost-effectiveness of tafamidis therapy and its potential effect on US healthcare spending. DiStefano et al. (2021)[6] examined the added therapeutic benefit of ultra-expensive drugs prescribed to Medicare Part D beneficiaries. Egilman et al. (2024)[7] compared prices based on efficiency frontiers with traditional cost-effectiveness analysis prices for biologic therapies. Balijepalli et al. (2024)[8] reviewed the impact of willingness-to-pay thresholds on price reduction recommendations for oncology drugs, highlighting the potential impact on timely access to life-saving medications. These studies collectively demonstrate the importance of reducing drug prices to improve access to medications and reduce healthcare costs.

It is evident that previous research on drug pricing often utilized static analytical methods, which fail to capture the dynamic complexity of drug price adjustments. Additionally, the majority of scholars have focused on the singular benefits of drug pricing, segregating the interactions among government, patients, and pharmaceutical companies for study. However, constrained by unidimensional analyses, such studies frequently overlook the comprehensive impact of drug price adjustments on both the pharmaceutical market and patient welfare. In contrast, this study employs system dynamics methodology, allowing for the comprehensive consideration of dynamic changes and intricate feedback mechanisms during drug price adjustments. By constructing dynamic models, we can more accurately simulate and predict the trends in drug prices, as well as evaluate the effects under different policy and market scenarios. Furthermore, system dynamics methodology can unveil the dynamic feedback mechanisms and nonlinear effects of drug price adjustments, thereby providing a more scientific basis for government decision-making and market management.

3. Analysis of Benefits Derived from Reducing Pharmaceutical Prices

3.1. The Benefits to Patients

The reduction of drug prices has a direct and significant impact on patients. Firstly, the decrease in drug prices implies that patients will bear less financial burden when purchasing medications. For patients suffering from chronic diseases or requiring long-term medication, the reduction in drug prices can significantly alleviate their medical expenses burden, thereby enhancing their quality of life and level of healthcare coverage. Secondly, the reduction in drug prices contributes to improving the accessibility of healthcare services. High drug prices may hinder patients from accessing necessary medication, especially for low-income groups or those lacking medical insurance coverage. Therefore, the reduction in drug prices enables more patients to access necessary medication, thereby enhancing the accessibility and equity of healthcare services.

3.2. The Benefits to Governments

The reduction of drug prices also brings about a series of benefits for governments. Firstly, lowering drug prices contributes to controlling healthcare expenditures. High drug prices constitute a major source of government healthcare expenditures, and reducing drug prices will alleviate the financial burden on governments, thereby enhancing the efficiency of healthcare resource utilization and the level of public health. Secondly, lowering drug prices helps to improve healthcare coverage. Governments can ensure that patients have access to necessary medication by implementing reasonable drug pricing policies, thereby enhancing the fairness and accessibility of healthcare coverage.

3.3. The Benefits in Terms of Social Equity

The reduction of drug prices holds significant importance in enhancing social equity and fostering social development. Firstly, lowering drug prices helps to reduce wealth disparities. High drug prices often make it difficult for low-income groups to afford necessary medication, exacerbating wealth

disparities in society. Lowering drug prices enables more patients to access necessary medication, thereby contributing to the reduction of social inequality. Secondly, lowering drug prices facilitates the advancement of public health. By reducing drug prices, better access to necessary medication for patients can be ensured, thereby reducing the spread and prevalence of diseases, enhancing the overall health level of society, and promoting sustainable social development.

4. Construction of System Dynamics Model

4.1. System Dynamics Conception of the Model

This system dynamics model involves various variables within the healthcare system, including changes in drug prices, quality of medical services, demand for healthcare services, stability of the healthcare supply chain, and patients' health levels. The system dynamics conception of the model is as follows:

(1) Patients' health levels are influenced by multiple factors: Improvements in service quality may promote patient recovery and enhance health levels, while increased financial burden can reduce the likelihood of patients seeking medical care[9], thereby lowering health levels. Higher stability in the healthcare system benefits patients' health levels.

(2) Medical service quality, demand, and healthcare supply chain stability are interrelated variables. For instance, as medical service quality improves, patient demand for services may increase since they are more willing to seek medical help. Enhanced service quality can also promote supply chain stability by increasing reliability and efficiency. However, improvements in service quality may also raise medical service costs[10].

(3) Government intervention impacts medical costs and patient financial burden: Government negotiation strategies and capabilities can affect the extent of drug price reductions[11,12]. Drug prices influence patients' financial burden and healthcare-seeking behavior, subsequently affecting patients' health levels. Patients' financial burden, in turn, can influence policy negotiation strategies. For example, if patients' financial burden is excessively high, the government might adopt a more stringent negotiation strategy to achieve greater drug price reductions considering public welfare concerns.

(4) The relationship between pharmaceutical companies' profits and research innovation: Pharmaceutical companies' profits may affect their investment in research and innovation. Higher profits can encourage companies to invest more in R&D, improving drug efficacy and advancing medical technology[13].

(5) Changes in drug prices can affect patient demand for drugs. Price reductions may increase demand, but this also depends on patients' income levels and the price elasticity of drug demand.

Based on the above conception, multiple causal loop diagrams were constructed involving variables related to patients, the government, and medical services, and these were analyzed both individually and interactively. Subsequently, the types of variables within the system were defined and clarified. Finally, the variables in the model were categorized according to their nature, with the primary types being state variables (Pharmaceutical Prices, Patient Financial Burden, Patients' health levels, Quality of Healthcare Services, Pharmaceutical Company Profits, Social Equity, Stability of the Healthcare Supply Chain System, Costs of the Healthcare Services System, Pharmaceutical Efficacy), rate variables (Drug Price Reduction Magnitude, Pharmaceutical Demand), auxiliary variables (Patient Medication Costs, Patients' healthcare-Seeking Behavior, Demand for Healthcare Services, Patients' healthcare-Seeking Behavior), and constants (Degree of Competition, Profit Margin, Physician Prescribing Behavior, Target Value for Stability of the Healthcare Supply Chain System, Target Value for Quality of Healthcare Services, Target Value for Social Equity, Patient Income Level etc.). The system flow diagram depicting changes in drug prices was established by describing and connecting the variables using flow diagram symbols, as shown in Figure 1.

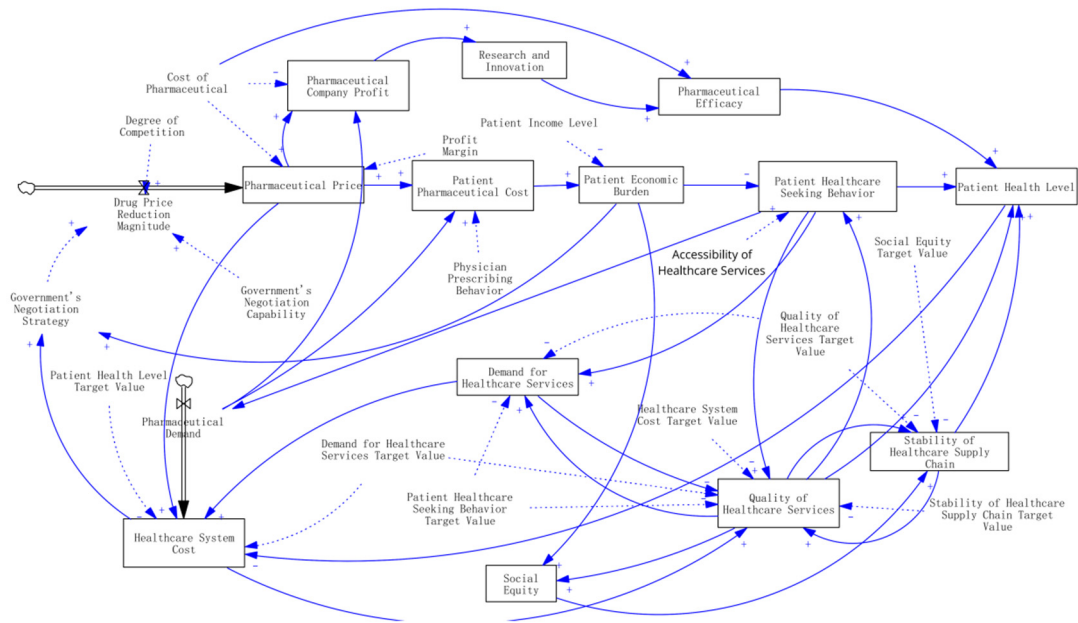


Figure 1. The system flow diagram depicting changes in drug prices

4.2. System Equation Construction

Based on the analysis of benefits, quantitative descriptions of the relationships between variables in the system stock-flow diagram were established using the DYNAMO language in Vensim software. The system dynamics equations constructed are as follows:

- 1) INITIAL TIME = 0; Units: Quarter
- 2) FINAL TIME = 10; Units: Quarter
- 3) TIME STEP = 1 Units: Quarters; [0,10]
- 4) Accessibility of Healthcare Services=0.6; Units: 1; [0,1,0.5]
- 5) Degree of Competition = 0.6; Units: 1; [0,1]
- 6) Government's Negotiation Capability=0.6; Units: 1
- 7) Government's Negotiation Strategy= $1/(1+\text{EXP}(-\text{Social Equity}))$; Units: 1
- 8) Cost of Pharmaceutical = 50; Units: yuan; [0, ?]
- 9) Drug Price Reduction Magnitude = Government's Negotiation Strategy * Government's Negotiation Capability * Degree of Competition; Units: 1
- 10) Patient Economic Burden = Pharmaceutical Price * Pharmaceutical Demand/Patient Income Level; Units: 1; [0,1]
- 11) Patients' health Level = INTEG (Patients' healthcare Seeking Behavior * Pharmaceutical Efficacy, 0); Units: 1
- 12) Patients' health Level Target Value == 0.8; Units: 1
- 13) Patients' healthcare Seeking Behavior= INTEG (Accessibility of Healthcare Services * (1-Patient Economic Burden), 0); Units: 1

- 14) Patient Income Level = RANDOM NORMAL(300, 2000 , 500 , 0 , 1000); Units: 1
- 15) Physician Prescribing Behavior = 0.5; Units: 1; [0,1]
- 16) Patients' healthcare Seeking Behavior Target Value ==0.8; Units: 1
- 17) Patient Pharmaceutical Cost = INTEG (Physician Prescribing Behavior * Pharmaceutical Price * Pharmaceutical Demand, 0); Units: yuan; [0,1]
- 18) Stability of Healthcare Supply Chain= INTEG ((1/(1+EXP(-(Social Equity - Social Equity Target Value)))) * (1/(1+EXP(-(Quality of Healthcare Services-Quality of Healthcare Services Target Value))))), 0); Units: 1
- 19) Stability of Healthcare Supply Chain Target Value==0.9; Units: 1
- 20) Healthcare System Cost= INTEG ((1/(1+EXP(-(Demand for Healthcare Services-Demand for Healthcare Services Target Value)))) * (1/(1+EXP(-(Patient Income Level-Patient Income Level Target Value)))) * Pharmaceutical Price * Pharmaceutical Demand, 0); Units: 1; [0,1]
- 21) Healthcare System Cost Target Value == 0.8; Units: 1
- 22) Quality of Healthcare Services= INTEG((1/(1+EXP(-(Stability of Healthcare Supply Chain-Stability of Healthcare Supply Chain Target Value)))) * (1/(1+EXP(-(Healthcare System Cost-Healthcare System Cost Target Value)))) * (1/(1+EXP(-(Demand for Healthcare Services-Demand for Healthcare Services Target Value)))) * (1/(1+EXP(-(Patients' healthcare Seeking Behavior-Patients' healthcare Seeking Behavior Target Value))))), 0); Units: 1; [0,1]
- 23) Quality of Healthcare Services Target Value == 0.9; Units: 1
- 24) Demand for Healthcare Services = INTEG ((1/(1 + EXP(- (Quality of Healthcare Services-Quality of Healthcare Services Target Value)))) * (1/(1+EXP(- (Patients' healthcare Seeking Behavior - Patients' healthcare Seeking Behavior Target Value))))), 0); Units: 1; [0,1]
- 25) Demand for Healthcare Services Target Value == 0.8; Units: 1
- 26) Pharmaceutical Company Profit = INTEG ((Pharmaceutical Price-Cost of Pharmaceutical) * Pharmaceutical Demand, 0); Units: yuan; [0,1]
- 27) Pharmaceutical Demand = 50; Units: **undefined** ; [0, ?]
- 28) Research and Innovation = INTEG (1/(1+EXP(-Pharmaceutical Company Profit)), 0); Units: yuan; [0,1]
- 29) Pharmaceutical Efficacy = (1/(1+EXP(-Cost of Pharmaceutical))) * (1/(1+EXP(-Research and Innovation))); Units: 1 [0,1]
- 30) Pharmaceutical Price = Cost of Pharmaceutical * (1+Profit Margin) * (1-Drug Price Reduction Magnitude); Units: yuan
- 31) Profit Margin = 0.3; Units: 1
- 32) Social Equity = INTEG (Patients' health Level, 0); Units: 1; [0,1]
- 33) Social Equity Target Value == 0.8; Units: 1; [0,1]

34) SAVEPER = TIME STEP; Units: Quarters; [0,10]

4.3. Model Simulation and Result Analysis

Project parameters were input into the constructed system dynamics model for the societal benefits of drug price reduction. The system simulation time step was set to one quarter, with a simulation period of 10 quarters.

4.3.1. The Benefits to Patients

The impact of drug price reductions on patient behavior is shown in Figure 2(a). Over time, as drug prices decrease, patients gradually tend to seek medical care rather than forgo treatment, resulting in an increase in patients' healthcare-seeking behavior. As the magnitude of the drug price reduction increases, drug prices continue to fall, thereby reducing the economic burden on patients. Consequently, patients are more likely to choose to seek medical care.

The changes in patient economic burden and health outcomes are illustrated in Figure 2(b). Over time, as the extent of drug price reduction increases, patient economic burden gradually decreases, and patients' health levels improve. This indicates that the reduction in drug prices alleviates the economic pressure on patients to some extent and enhances their health levels.

The changes in Pharmaceutical Efficacy is shown in Figure 2(c). The efficacy of pharmaceuticals demonstrates an observable increase, albeit modest, with diminishing growth rates over extended periods. Consequently, within certain bounds, price reductions of pharmaceuticals may incentivize enterprises to intensify research and development efforts to enhance efficacy, thereby bolstering competitiveness. However, excessively low drug prices could impinge upon company profits, consequently constraining investments in scientific research and innovation.

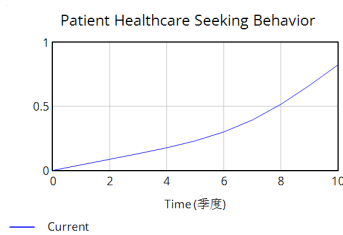


Figure 2.(a) Changes in Patient Healthcare-Seeking Behavior Over Time

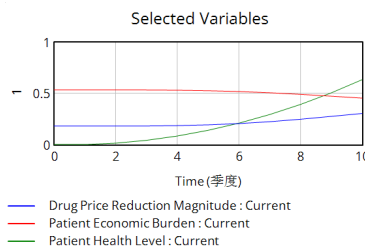


Figure 2.(b) The Impact of Drug Price Reduction Magnitude on Patients

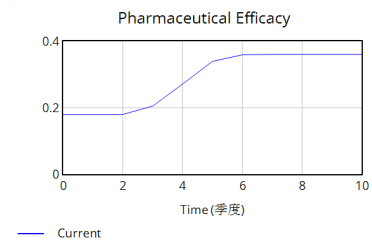


Figure 2.(c) Pharmaceutical Efficacy

4.3.2. The Benefits to Governments

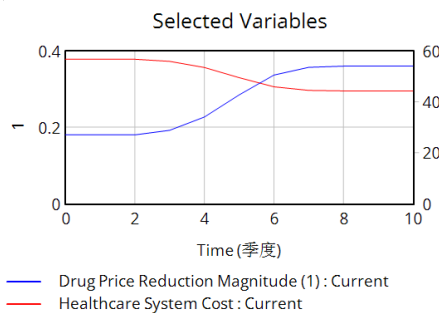


Figure 3. Healthcare System Cost

The variation of healthcare system costs over time is depicted in Figure 3. As illustrated, the Drug Price Reduction Magnitude increases gradually, stabilizing within a certain range. Concurrently, healthcare system costs decrease progressively. The government aims to mitigate healthcare system

costs by reducing pharmaceutical prices, thereby reallocating more funds toward enhancing healthcare service quality and subsequently elevating the overall population health status.

4.3.3. The Benefits in Terms of Society

Changes in the quality of healthcare services and social equity are illustrated in Figure 4. As shown, over time, the magnitude of drug price reductions increases, leading to a gradual improvement in the quality of healthcare services. However, analyzing the trend indicates that the ultimate target value may not be achieved. Concurrently, the value of social equity also increases. This suggests that reasonable reductions in drug prices are beneficial to the improvement of healthcare service quality. The likely reason is that lower healthcare service prices enhance patients' willingness to seek medical care, which, within certain limits, increases the demand for healthcare services. Consequently, the profits of healthcare institutions grow, fostering improvements in the quality of healthcare services and, thereby, enhancing social equity.

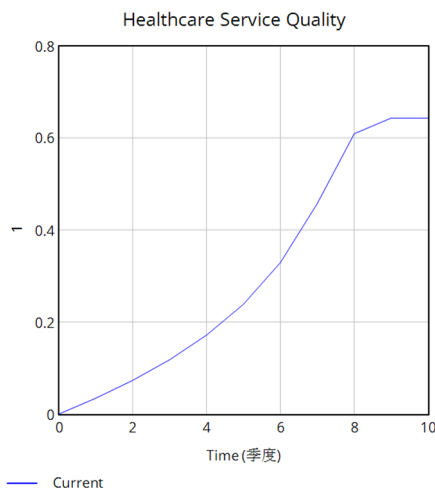


Figure 4(a). Quality of Healthcare Services

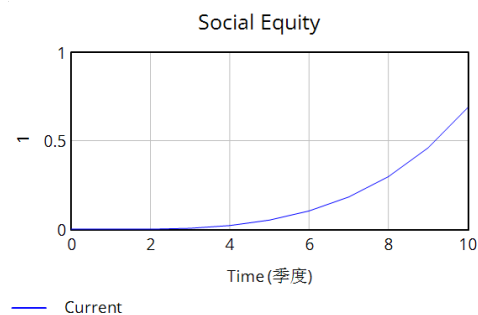


Figure 4(b). Social Equity

5. Conclusion and Limitations

Based on the findings of the system dynamics model, drug price reduction demonstrates significant societal benefits. As drug prices decrease, there is a gradual decline in the costs of the healthcare services system, implying that more funds can be reallocated towards enhancing the quality of healthcare services. By improving healthcare service quality, overall health levels are elevated, resulting in long-term societal health benefits. Furthermore, drug price reduction policies also alleviate patients' financial burdens, enabling more individuals to access necessary healthcare services, thus fostering social equity and fairness. Overall, drug price reduction policies not only effectively enhance the economic efficiency of healthcare service systems but also promote the overall health and equity development of society.

However, there are several limitations to the model. Firstly, it may oversimplify the complexity of the real world, including overlooking potential nonlinear relationships and interactions among causal factors. Secondly, the accuracy of the model's parameters and input data may be constrained, which could affect the reliability of its predictive outcomes. Additionally, the model may not account for certain important factors such as cultural differences, policy changes, or technological advancements, which could impact its effectiveness and applicability. In conclusion, while drug price reduction policies hold promise for generating positive societal benefits, further refinement and validation are necessary to ensure their effectiveness and sustainability in real-world applications.

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