Study of the Impact of the Internet of Things Integration on Competition Among 3PLs

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***Abstract*—The Third-Party Logistics (3PL) industry plays an important role in modern supply chains, facilitating the efficient movement of goods and optimizing logistics operations. With the advent of advanced technologies, such as the Internet of Things (IoT), automation, artificial intelligence, and data analytics, the landscape of the 3PL industry has undergone significant transformation. With their tracking ability and real time data enabling capability, IoT technologies have gained great attention from researchers and practitioners and have been widely used in the supply chain sector. This paper employs the Cournot duopoly model within the framework of game theory to investigate the profound implications of the use of IoT technology on competition and operational strategies within the 3PL sector. In this study, we construct a Cournot duopoly model focusing on the assessment of the service level of third party logistics (3PL) within the market. We consider variables such as service level and the IoT adoption rates as crucial factors influencing the behavior of these firms. Through numerical simulations we quantify the impact of the technology on the overall profitability for both firms. Our findings have demonstrated the positive impact of integrating IoT on enhancing the profits of the 3PL firms. Additionally, the IoT adoption rates and the overall IoT integration costs play a critical role in determining market equilibrium and profit distribution.**

Keywords*—Internet of things; third party logistics; game theory; cournot duopoly

I. INTRODUCTION

In recent years, the supply chains have faced crucial changes due numerous factors such as the pandemic crisis, increasing customer demands in terms of better quality products, quicker lead times and personalized experiences. Furthermore, in light of the emergence of new international markets, the growth of e-commerce and an increasing awareness of the importance of sustainability, the supply chains operations have become greatly complex. Consequently, there is a pressing need to adopt a fresh perspective on supply chain management by embracing the shift to digitalized sustainable operations. In order to meet the ever-changing demands of customers, the adoption of a sustainable supply chain (SSC) has become imperative for companies. Over the past few decades, there has been a notable increase in the number of studies focusing on sustainable supply chain management (SSCM).

Furthermore, organizations strive to enhance their business processes by implementing technologies aligned with industry 4.0 (I4.0). This latter is revolutionizing the current industrial landscape, bringing about a significant shift in paradigms. I4.0 encompasses various technologies. Internet of Things (IoT), artificial intelligence (AI), blockchain, and the physical internet have become ubiquitous terms in describing the modern world. These digital technologies enable the generation, collection and analysis of vast volumes of data from diverse sources, including ERP systems, mobile devices, customer purchasing behavior, product lifecycle operations, global positioning systems (GPS), radio frequency identification (RFID) tracking, surveillance videos, IoT sensors etc. Incorporating these technologies into the value chain increases flexibility, efficiency, productivity and ensure a better decision-making process [1].

The Internet of Things (IoT) is a global platform that enables the connection of smart devices through the Internet. It facilitates the seamless integration of the supply chain (SC) and communication technology (ICT) infrastructure within an organization, as well as with customers and suppliers externally. Exploring the impact of the internet of things technologies on the supply chain processes have attracted the interest of many researchers [2]–[6]. IoT has proved its impact on promoting sustainability in the supply chains, through its capability to ensure visibility traceability and real time decision making.

On the other hand, the complexity of the supply chain operations, the increased costs and intense competitiveness in the global business world have led manufacturers and businesses to consider outsourcing their logistics activities to experts while focusing on their core competencies. Fast and reliable transportation has become essential, which may lead to higher transportation costs, making 3PL services necessary [7]

Third-Party Logistics (3PL) refers to the practice of engaging external companies to manage some or all of the logistics tasks for a company. 3PL firms primarily offered transportation services. However, due to the increasing competitiveness and continuous demanding customers' needs, 3PL companies have seen the obligation to incorporate a wider range of services and specializations such as now conventional and refrigerated transportation, smart warehousing [8] as well as focusing on developing their IT skills and widen their expertise [7] and providing sustainable activities and strategies [9].

Logistics requirements and expectations have evolved in recent years in view of the continuous developments in advanced technologies and the industry 4.0 revolution. Embracing cutting-edge technologies brings numerous advantages, such as increased operational efficiencies in transportation and warehousing, as well as effective risk management. Therefore, 3PL companies ought to implement suitable information technology that aligns with their customers' needs [10].

Literature related to the 3PL market is enriched constantly, [11], [12] propose third party logistics selection frameworks using the MCDM approach,[13] explores the challenges and value of adopting the blockchain the 3PL companies. Moreover, various decision-making models for evaluating and selecting 3PL from a sustainability point of view [14]–[18]. Outsourcing logistics activities offers numerous advantages such as better flexibility and overall greater economic benefits [9], which has driven the third-party service providers market to flourish. However, the rise in 3PL companies have resulted in increased competition among them [8].

Game theory approach is one of the preferred mathematical models used in supply chain management. Considering the structure of the supply chain and their many players, game theory offers a thorough mathematical approach helping analyzing and optimizing the decision making and configurations of the supply chains [19]. The author in [20] used game theory approach to study the impact of open innovation for achieving competitive advantage. The author in [9] used game theory to investigate the pricing strategies of 3PL for a sustainable supply chain focusing on decreasing carbon emissions and delivery time. Similarly, [21] focused on pricing decisions in three different strategies considering CSR concerns and introducing a greening degree while [22] focused on investment decisions investigating who will bear the implementation cost of the IoT.

The main objective of the theoretical games in the literature focuses on pricing decision, decision to outsource and decision to investment costs. Although the use of game theory in supply chain is fairly extensive, its use in relation to 3PL, sustainability and IoT impact is under-researched. Strategy making under competitiveness remains challenging [8]. This research will consider a duopoly competition between two 3PL firms in a homogenous environment. The mathematical model will investigate the impact of the integration of the IoT technologies on the performance and quality of service of the 3PL firms.

This research investigates the following questions:

- How sensitive is the 3PL firms profit to changes in the integration rate of the IoT?
- Can IoT be added to a strategy set to enhance the competitiveness in the market of third party logistics?

The paper will be organized as followed: Section II will present a literature review of the streams of research related to our scope, Section III will describe our mathematical model, Section IV presents and discusses a numerical analysis of our model, and lastly a conclusion of our findings will be presented in Section V.

II. Literature Review

Supply chains remain one of the most challenging to manage considering their complex structure. In view of increasing customer demands; for better service, better lead times and more sustainable service, more businesses opt for outsourcing their logistics operations in order to focus on their core expertise [18]. Third party logistics providers, also known as 3PL are a well-established logistics business that offer various logistics services. They carry out numerous tasks and activities based on the need of their customer. Their main primary service consists of transportation, however warehousing, inventory management, traceability and many other supply chain activities are carried out. Many studies have pointed out the benefits of outsourcing logistics related activities to third parties. Reducing logistics related costs as well as focusing on the company's core expertise is considered the reasons companies choose to outsource to 3PL providers [17], [18]. Other benefits include better flexibility, higher logistics performance, higher quality better and strategic and operational risk management and sustainability [17]. Research has pointed out that 3PL providers are crucial to attain supply chain sustainability [7].

In these past decades, the business world has seen a drastic change in its operational and strategic levels thanks to the introduction of cutting age technologies in light of the industry 4.0 revolution. Big data analytics, IoT, Artificial intelligence, cloud technology, cybersecurity, and robotics bring important opportunities for the improvement of the supply chain performance and efficiency. The implantation of these technologies throughout the value chain leads to an increased flexibility, efficiency, productivity and better decision-making processes [1]. IoT technologies are one of the main drivers of the shift to a more connected world, enabling traceability and visibility throughout the whole value chain [3], [23].

The application of the internet of things technologies are majorly in the logistics sector [24]. Their use in different stages of the supply chain is not new, however rapid development of technologies brings new opportunities and innovative ways to enhance the logistics operation performance. RFID QR code NFC GPS and other IoT technologies have been adopted extensively achieving a transparent and efficient environment. The shift to a digitalized value chain has brought new value-added services through internet of things, automation big data AI, etc. [25].

As the third-party logistics market has expanded considerably, competition has increased. Shifting to a smart tech driven 3PL provider is a must. Researchers showed their interest in the adoption of the IoT technologies to enhance their performance and decision-making process [26]. Several works have been conducted in relation to the use of IoT in the 3PL market, [27], [28] proposed IoT enabled systems for warehousing management, while [29] proposed an IoT based just in time milk run routing system and [30] proposed an IoT based just in time milk run routing system presented a delivery system architecture for coordinating IoT infrastructure and 3PL service. IoT technologies can be used in different core processes of 3PL services enabling real time logistics, enhanced flexibility and overall improved efficiency of logistics operations. However, this field remains under-researched requiring further developments in order to take advantage of these cutting-edge technologies [31]. On the other hand, shifting to a smart tech driven logistics remain a challenge, mainly due to cost of investments.

III. Model Description

The SC network comprises two 3PL firms competing in a duopoly environment and multiple suppliers with 3PL as presented in Fig. 1.

We consider a market setting where P_1 and P_2 are two 3PL firms offering their services to N suppliers. The 3PL firms compete in the market by selecting the quantity of service that will maximize their profit. We consider the game is simultaneous and in a fixed period t.

In Cournot setting, the two firms offer the same service. The demand function represents the relationship between the total quantity of service demanded by all consumers in the market and the price at which it is offered. The inverse linear demand function is expressed as:

$$P(S) = a - b * S$$

where, S is the total service in the market, $P(S)$ is the price of the service, a and b are positive constants relative to the market

Within the Cournot model, which examines the actions of firms competing through output quantities rather than prices, the demand function is a critical component. In this framework, each individual firm considers the output of other firms as a constant and subsequently establishes its own output level to maximize their profit.

The firms offer a number of services namely transportation, warehousing inventory management customs and compliances, technology solutions, etc.

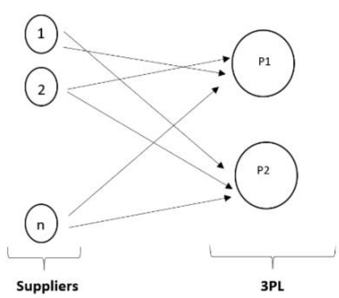

Fig. 1. The model chosen market setting comprising 3PL and suppliers.

In order to remain competitive, the firms have invested in the IoT technology to shift to a digitalized supply chain and to foster sustainability.

The use of IoT ensure a transparent and efficient value chain, greener supply chains, reduced emissions, improved lead times, and optimized costs [23], [32].

This paper considers that the firms decide to integrate the technology. We thus consider a parameter $\beta_i \epsilon [0,1]$ that corresponds to the integration rate of Internet of Things. The marginal cost function of a firm i is as follows:

$$C(S_i) = c * S_i + C_i^{inv} + C_i^{IoT} S_i \tag{1}$$

where

$$C_i^{inv} = \beta_i C_0 \tag{2}$$

$$C_i^{IoT} = \beta_i C_m \tag{3}$$

The marginal cost of firm i in terms of $S_i \, and \, \beta_i$ is as follows:

$$C(S_i, \beta_i) = c * S_i + \beta_i (C_0 + C_m S_i) \tag{4}$$

Eq. (2) represents the investment cost in IoT of firm i which depends on the degree to which the technology is incorporated β_i, this cost is additionally adjusted by a fixed cost of investment in the IoT technology C_0. Eq. (3) corresponds to the cost of the use of IoT. It implies that the cost of the IoT use for a firm i is influenced by how extensively IoT technology is integrated in that firm β_i, and this cost is further scaled by the baseline cost of using IoT technology C_m.

Eq. (4) represents the marginal cost of the firms i depending on the service level S_i and their IoT integration rate β_i. According to the equation, when a firm haven't implemented the IoT technology its cost is equal to c, which corresponds to the basic cost of service, whereas implementing IoT induces additional charges.

The main challenge of the digitization of the supply chain and the implementation of the industry 4.0 technologies lies in their high investment cost [33]. Hence, we consider two costs related to IoT, the investment cost and the costs engendered by the exploitation of the technology such as maintenance, training, etc.

Considering the expenses associated with planning and implementing IoT initiatives in logistics, the involvement of government regulations becomes pivotal in incentivizing various industries and services [24]. We thus consider in our paper a government incentive function defined as follows:

$$I(\beta_i) = A \ln(1 + \beta_i) \tag{5}$$

where, A is constant factor that determines the scale of the incentive. In the real world, the government encouragements and incentives have a limit, thus the choice of a logarithmic function. According to (5), as the rate increases, the logarithmic component represents the diminishing returns phenomenon, where the reward gradually becomes less significant.

Based on the aforementioned, the profit function is presented as follows:

$$\Pi(\mathrm{Si}) = \mathrm{TR}(\mathrm{Si}) - C(\mathrm{Si}) + \mathrm{I}(\beta_i)\mathrm{S_i} \tag{6}$$

Where TR(Si) is the total revenue function for firm i defined as: $TR(S_i) = P(S) \cdot S_i$

$$TR(S_i) = \left(a - b(\textstyle\sum_{k \neq i} s_k + (S_i))\right) S_i = -bS_i^2 + a - bS_i \textstyle\sum_{k \neq i} s_k \tag{7}$$

Substituting (4), (5) and (7) in (6), the profit equation for firm i is:

$$\Pi_i(S_i, \beta_i) = -bS_i^2 + aS_i - bS_i \textstyle\sum_{k \neq i} s_k - c * S_i - \beta_i (C_0 + C_m S_i) + A \ln(1 + \beta_i) S_i \tag{8}$$

The marginal profit of the firm is expressed as follows:

$$\frac{\partial \Pi_i(S_i,\beta_i)}{\partial S_i} = -2bS_i + a - b\sum_{k\neq i} s_k - c - \beta_i C_m + A\ln(1+\beta_i) \quad (9)$$

Since the objective function is concave as $\frac{\partial^2 \Pi_i(S_i,\beta_i)}{\partial^2 S_i} = -2b < 0$, the reaction function of firm i is expressed as follows considering $\frac{\partial \Pi_i(S_i,\beta_i)}{\partial S_i} = 0$

$$S_i^*(\beta_i) = \frac{a - b\sum_{k\neq i} s_k - c}{2b} + \frac{-\beta_i C_m + A\ln(1+\beta_i)}{2b} \quad (10)$$

This work focuses in the case of a duopoly market setting, the profit equation for firm 1 and 2 are:

$$\Pi_1(S_1,\beta_1) = -bS_1^2 + S_1[a - c - \beta_1 C_m - bS_2 + A\ln(1+\beta_1)] - \beta_1 C_0 \quad (11)$$

$$\Pi_2(S_2,\beta_2) = -bS_2^2 + S_2[a - c - \beta_2 C_m - bS_1 + A\ln(1+\beta_2)] - \beta_2 C_0 \quad (12)$$

And the reaction function for firm 1 and 2 are:

$$R_1(S_1) = \frac{a - bS_2 - c}{2b} + \frac{-\beta_1 C_m + A\ln(1+\beta_1)}{2b} \quad (13)$$

$$R_2(S_2) = \frac{a - bS_1 - c}{2b} + \frac{-\beta_2 C_m + A\,ln(1+\beta_2)}{2b} \quad (14)$$

$$\text{Let} \quad \begin{cases} x_1 = -\beta_1 C_m + A\ln(1+\beta_1) \\ x_2 = -\beta_2 C_m + A\ln(1+\beta_2) \\ a_0 = a - c \end{cases} \quad (15)$$

S_1^* and S_2^* at the Cournot equilibrium are thus expressed as:

$$S_1^*(\beta_1,\beta_2) = \frac{1}{3b}(2x_1 - x_2 + a_0) \quad (16)$$

$$S_2^*(\beta_1,\beta_2) = \frac{1}{3b}(2x_2 - x_1 + a_0) \quad (17)$$

Provided that $2x_1 - x_2 + a_0 > 0$ and $2x_2 - x_1 + a_0 > 0$

According to this result, in the case where neither firm decides to integrate IoT; $S_1^*(0,0) = S_2^*(0,0) = \frac{a_0}{3b}$,both firms reach the same equilibrium output. Furthermore, if firm 1 chooses the strategy to integrate the IoT while the firm 2 chooses not to integrate, their optimal service level is: $S_1^*(1,0) = \frac{2(-C_m + A\ln 2) + a_0}{3b}$, $S_2^*(1,0) = \frac{-(-C_m + A\ln 2) + a_0}{3b}$ and $\Delta s = \frac{-C_m + A\ln 2}{b}$. In this case, the service level that firm 1 has to provide in this case depends on the government incentive and the cost of the use of IoT. If $\ln 2 > C_m$, meaning the government incentive is much greater than the IoT exploitation cost, firm1 has to provide greater service level than firm 2. On the contrary, if the incentive is inferior to the IoT exploitation costs firm 2 should provide greater service level than firm 1.

After finding the Cournot equilibrium, it is observed that the equilibrium points depend on β_1 and β_2. It shows that the integration of IoT influences the equilibrium. Therefore, in the second stage, we will analyze the profit with respect to β_1 and β_2.

A. Second Stage Equilibrium Analysis

The profit function in terms of the integration rate β_i by taking (16), (17) in (11), (12):

$$\Pi_1(S_1,\beta_1) = \frac{4x_1(x_1 - x_2 + a_0) + x_2(x_2 - 2a_0) + a_0^2}{9b} - \beta_1 C_0$$

$$\Pi_2(S_2,\beta_2) = \frac{4x_2(x_2 - x_1 + a_0) + x_1(x_1 - 2a_0) + a_0^2}{9b} - \beta_2 C_0$$

Thus, the profit function in terms of β_1, β_2 is:

$$\begin{cases} \Pi_1(\beta_1,\beta_2) = \frac{4(-\beta_1 C_m + A\ln(1+\beta_1))^2 + 4(-\beta_1 C_m + A\ln(1+\beta_1))(\beta_2 C_m - A\ln(1+\beta_2) + a_0)}{9b} + \frac{(-\beta_2 C_m + A\ln(1+\beta_2))(-\beta_2 C_m + A\ln(1+\beta_2) - 2a_0) + a_0^2}{9b} - \beta_1 C_0 \\ \Pi_2(\beta_1,\beta_2) = \frac{4(-\beta_2 C_m + A\ln(1+\beta_2))^2 + 4(-\beta_2 C_m + A\ln(1+\beta_2))(\beta_1 C_m - A\ln(1+\beta_1) + a_0)}{9b} + \frac{(-\beta_1 C_m + A\ln(1+\beta_1))(-\beta_1 C_m + A\ln(1+\beta_1) - 2a_0) + a_0^2}{9b} - \beta_2 C_0 \end{cases} \quad (18)$$

The profit equation for both firms enables the calculation of the maximum local profit based on the IoT integration rate. Thus, the derivative of the system is:

$$\begin{cases} \frac{\partial \Pi_1(\beta_1,\beta_2)}{\partial \beta_1} = \frac{4}{9b}\left(\frac{A}{(1+\beta_1)} - C_m\right)(2x_1 - x_2 + a_0) - C_0 \\ \frac{\partial \Pi_1(\beta_1,\beta_2)}{\partial \beta_2} = \frac{2}{9b}\left(\frac{A}{(1+\beta_2)} - C_m\right)(x_2 - 2x_1 - a_0) \end{cases} \quad (19)$$

By substituting (15) in (19) our system of derivatives is expressed as:

$$\begin{cases} \frac{\partial \Pi_1(\beta_1,\beta_2)}{\partial \beta_1} = \frac{4}{9b}\left(\frac{A}{(1+\beta_1)} - C_m\right)(-2\beta_1 C_m + 2A\ln(1+\beta_1) + \beta_2 C_m - A\ln(1+\beta_2) + a_0) - C_0 \\ \frac{\partial \Pi_1(\beta_1,\beta_2)}{\partial \beta_2} = \frac{2}{9b}\left(\frac{A}{(1+\beta_2)} - C_m\right)(-\beta_2 C_m + A\ln(1+\beta_2) + 2\beta_1 C_m - 2A\ln(1+\beta_1) - a_0) \end{cases} \quad (20)$$

Solving $\frac{\partial \Pi_1(\beta_1,\beta_2)}{\partial \beta_1} = \frac{\partial \Pi_1(\beta_1,\beta_2)}{\partial \beta_2} = 0$ simultaneously, the optimal equilibrium solution can be derived:

The solution for $\frac{\partial \Pi_1(\beta_1,\beta_2)}{\partial \beta_2} = 0$ is either $\beta_2 = \frac{A}{C_m} - 1$ or $x_2 - 2x_1 - a_0 = 0$ .However, according to (16) $x_2 - 2x_1 - a_0 < 0$ thus $\beta_2 = \frac{A}{C_m} - 1$. By replacing $\beta_2 = \frac{A}{C_m} - 1$ in (20) we get:

$$\frac{4}{9b}\left(\frac{A}{(1+\beta_1)} - C_m\right)\left(-2\beta_1 C_m + 2A\ln(1+\beta_1) + \left(\frac{A}{C_m} - 1\right)C_m - A\ln\left(\frac{A}{C_m}\right) + a_0\right) = C_0 \quad (21)$$

Knowing $\lim_{x\to\infty} \frac{\ln(1+x)}{1+x} = \varepsilon$, we consider $\ln(1+\beta_1) = \varepsilon(1+\beta_1)$ .Considering $\beta_2 = \frac{A}{C_m} - 1$ and $\beta_2 \epsilon [0,1]$ we assume $A \approx C_m$ since $C_m \leq A \leq 2C_m$ .Taking the latter in consideration in (21) we get,

$$\beta_1^2 2C_m(A\varepsilon - C_m) + \beta_1\left(\frac{8}{9b}(C_m - A\varepsilon) + C_m(1 + a_0) + C_0\right) + C_0 - \frac{4}{9b}(2A\varepsilon + a_0) = 0 \quad (22)$$

Finding the solution for (22) we calculate the $\Delta = \left(\frac{8}{9}(C_m - A\varepsilon) + C_m(1 + a_0) + C_0\right)^2 + 8C_m(A\varepsilon - C_m)\left(\frac{4}{9b}(2A\varepsilon + a_0) - C_0\right)$. To guarantee that our equation accepts real solutions the following condition must be met $\Delta > 0 \Rightarrow 9bC_0 < 4(2A\varepsilon + a_0)$. The solution is thus:

$$\beta_1 = \frac{-\left(\frac{8}{9b}(C_m - A\varepsilon) + C_m(1 + a_0) + C_0\right) \pm \sqrt{\Delta}}{4C_m(A\varepsilon - C_m)}$$

$$\beta_1 = \frac{-\left(\frac{8}{9b}(C_m - A\varepsilon) + C_m(1+a_0) + C_0\right)}{4C_m(A\varepsilon - C_m)} \pm \frac{\sqrt{\left(\frac{8}{9}(C_m - A\varepsilon) + C_m(1+a_0) + C_0\right)^2 + 8C_m(A\varepsilon - C_m)\left(\frac{4}{9b}(2A\varepsilon + a_0) - C_0\right)}}{4C_m(A\varepsilon - C_m)}$$

while $0 \leq -\left(\frac{8}{9b}(C_m - A\varepsilon) + C_m(1 + a_0) + C_0\right) \pm \sqrt{\Delta} \leq 1$

After finding the optimal equilibrium, we investigate whether the critical points are maximums by calculating the hessian matrix.

$$\mathrm{H}(\Pi_1(\beta_1, \beta_2)) = \begin{bmatrix} \mathrm{R}_1 & \mathrm{R}_2 \\ \mathrm{R}_3 & \mathrm{R}_4 \end{bmatrix}$$

Where

$$R_1 = \frac{\partial^2 \Pi_1(\beta_1, \beta_2)}{\partial^2 \beta_1}$$

$$R_2 = \frac{\partial^2 \Pi_1(\beta_1, \beta_2)}{\partial \beta_1 \partial \beta_2}$$

$$R_3 = \frac{\partial^2 \Pi_1(\beta_1, \beta_2)}{\partial \beta_2 \partial \beta_1}$$

$$R_4 = \frac{\partial^2 \Pi_1(\beta_1, \beta_2)}{\partial^2 \beta_2}$$

$$R_1 = \frac{4}{9b} . \frac{-2A^2 \ln(1+\beta_1) + 2A^2 - A(2C_m(\beta_1+2) + \varkappa_2 + a_0) + 2C_m^2(\beta_1+1)^2}{(1+\beta_1)^2} \quad (23)$$

$$R_4 = -\frac{2}{9b} . \frac{A^2(\ln(1+\beta_2) - 1) + A(C_m(\beta_2+2) + 2A\ln(1+\beta_1) - 2\beta_1 C_m - a_0) + C_m^2(-\beta_2^2 - 2\beta_2 - 1)}{(1+\beta_2)^2} \quad (24)$$

$$R_2 = \frac{4}{9b}\left(C_m - \frac{A}{\beta_2+1}\right)\left(\frac{A}{\beta_1+1} - C_m\right) \quad (25)$$

$$R_3 = \frac{4}{9b}\left(C_m - \frac{A}{\beta_1+1}\right)\left(\frac{A}{\beta_2+1} - C_m\right) \quad (26)$$

The first principal minor is $|H_1| = \frac{\partial^2 \Pi_1(\beta_1, \beta_2)}{\partial^2 \beta_1}$

$$|H_1| = \frac{4}{9b} . \frac{-2A^2 \ln(1+\beta_1) - A(2C_m(\beta_1+2) - \beta_2 C_m + A\ln(1+\beta_2) + a_0) + 2A^2 + 2C_m^2(\beta_1+1)^2}{(1+\beta_1)^2} \quad (27)$$

The second principal minor or the hessian determinant $|H_2| = R_1R_4 - R_2R_3$

$$|H_2| = R_1R_4 + \frac{4}{9b}\left(C_m - \frac{A}{\beta_2+1}\right)^2\left(\frac{A}{\beta_1+1} - C_m\right)^2 \quad (28)$$

Following the calculations, the function admits a local maximum when:

$$\begin{cases} R_1 < 0 \\ |H_2| > 0 \end{cases}$$ therefore, these conditions should be met:

$$-2A^2\ln(1+\beta_1) - A(2C_m(\beta_1+2) - \beta_2 C_m + A\ln(1+\beta_2) + a_0) + 2A^2 + 2C_m^2(\beta_1+1)^2 < 0$$

$$R_1R_4 + \frac{4}{9b}\left(C_m - \frac{A}{\beta_2+1}\right)^2\left(\frac{A}{\beta_1+1} - C_m\right)^2 \geq 0$$

when these conditions are met, the optimal equilibrium solution for firm 1 is

$$(\beta_1, \beta_2) = \left(\frac{-\left(\frac{8}{9b}(C_m - A\varepsilon) + C_m(1+a_0) + C_0\right) \pm \sqrt{\left(\frac{8}{9}(C_m - A\varepsilon) + C_m(1+a_0) + C_0\right)^2 + 8C_m(A\varepsilon - C_m)\left(\frac{4}{9b}(2A\varepsilon + a_0) - C_0\right)}}{4C_m(A\varepsilon - C_m)}, \frac{A}{C_m} - 1\right) \quad (29)$$

Following the same approach and calculations, the optimal equilibrium solution for firm 2 is given as:

$$(\beta_1, \beta_2) = \left(\frac{A}{C_m} - 1, \frac{-\left(\frac{8}{9b}(C_m - A\varepsilon) + C_m(1+a_0) + C_0\right) \pm \sqrt{\left(\frac{8}{9}(C_m - A\varepsilon) + C_m(1+a_0) + C_0\right)^2 + 8C_m(A\varepsilon - C_m)\left(\frac{4}{9b}(2A\varepsilon + a_0) - C_0\right)}}{4C_m(A\varepsilon - C_m)}\right) \quad (30)$$

IV. Numerical Analysis and Discussion

This part of the article focuses on performing a numerical analysis to investigate the impact of the parameters and the values of β_1 and β_2 on the profit of both firms. According to the model, we aim to assess the effects of the IoT integration rate on the profit of 3PL firms in a duopoly market, where we assume they offer identical services, at a fixed period t.

We first explored the impact of β on the incentives values. Fig. 2 shows the behavior of the incentive function depending on β and A.

According to the plot, we observe that modifications in integration rates result in proportional alterations in the incentive value. Nevertheless, the parameter A serves as a scaling factor for the incentive, influencing the magnitude of the incentive's response to changes in beta. A higher value of A magnifies the influence of beta on the incentive, whereas a smaller A diminishes this impact.

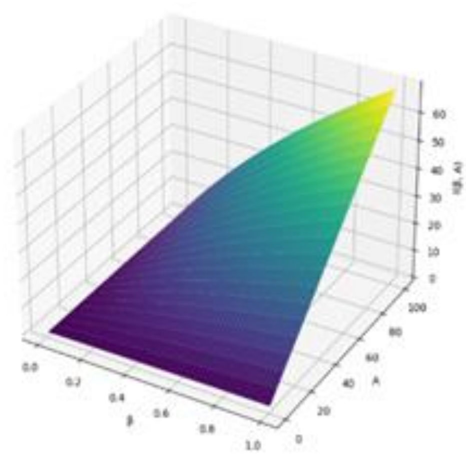

Fig. 2. Incentive function plot in terms of β.

We then analyzed the impact of β_1 and β_2 on the profit values. A data set of parameters have been examined in order to analyze the effect of the parameters and the values of β_1 and β_2 and on the profit values. Adjusting the values of C_m, A, a_0, b, C_0 will help see how different scenarios impact the profit landscape, in different IoT integration strategies. For this purpose, we considered four different cases.

A. Case 1: Firm 1 and Firm 2 Choose Not to Integrate IoT

The first case we investigate is when $\beta_1 = 0$ and $\beta_2 = 0$. Table I represents the value of π_1 the profit of firm 1 and π_2 the profit of firm 2 when both firms chose not to integrate IoT.

TABLE I. PROFIT VALUES OF FIRM 1 AND FIRM 2 AT $\beta_1 = \beta_2 = 0$

C_m	A	a_0	b	C_0	$\pi_1 = \pi_2$
15	20	40	1	10	168.888889
32	60	40	1	10	168.888889
45	80	40	1	10	168.888889
15	20	80	1	10	693.333333
32	60	80	1	10	693.333333
45	80	80	1	10	693.333333
15	20	60	1	10	386.666667
32	60	60	1	10	386.666667
45	80	60	1	10	386.666667
15	20	60	1	10	386.666667
32	60	60	1	10	386.666667
45	80	60	1	20	386.666667
45	50	60	1	20	386.666667
30	50	80	1	20	693.333333
0.8	1.2	6	0.5	0.2	5.333333
1	1.5	10	0.7	0.3	12.698413

B. Case 2 : Firm 1 and Firm 2 Integrate IoT at 100%

The second case we consider is when both firms integrate fully the IoT. Table II represents the value of $\pi 1$ the profit of firm 1 and $\pi 2$ the profit of firm 2 for $\beta 1=\beta 2=1$

The profits in this case are the same as well since they chose the same strategy of integrating IoT at 100%. In the same setting of the parameters comparing case 1 and case 2, the profits decreases due to additional costs of integrating IoT. However, in case 2 the incentives for integrating IoT impacts majorly on the profits. As the incentives increases the profits of the firms increases as well.

C. Case 3: Firm 1 Integrate IoT at 100% and Firm 2 does not Integrate IoT

After exploring the cases where both firms choose the same strategy, we consider the case where one firm integrates IoT fully while the other firm chooses not to integrate it. In Table III, we consider firm 1 integrates IoT at β_1=0, while firm 2 is at β_2=0.

TABLE II. PROFIT VALUES OF FIRM 1 AND FIRM 2 AT $\beta_1 = \beta_2 = 1$

C_m	A	a_0	b	C_0	$\pi_1 = \pi_2$
15	20	40	1	10	138.818208
32	60	40	1	10	339.573179
45	80	40	1	10	356.835944
15	20	80	1	10	643.048317
32	60	80	1	10	1034.48573
45	80	80	1	10	1067.08971
15	20	60	1	10	346.488818
32	60	60	1	10	642.585009
45	80	60	1	10	667.58384
15	20	60	1	10	346.488818
32	60	60	1	10	642.585009
45	80	60	1	20	657.518384
45	50	60	1	20	102.748488
30	50	80	1	20	841.338431
0.8	1.2	6	0.5	0.2	5.303033
1	1.5	10	0.7	0.3	12.650859

In this case the profits are differing from firm to another. The firm with higher integration rate has greater profit since the incentives increases the profits. C_0 also impacts the profits as C_0 increase the profits for the firm using IoT decreases.

D. Case 4: Both Firms Integrate IoT

The last case we consider is both firms integrate IoT but not at a rate β=1. Table IV presents a number of instances with various values for integration rates for both firms 1 and 2.

TABLE III. PROFIT VALUES OF FIRM 1 AND FIRM 2 AT β_1=1 AND β_2=0

C_m	A	a_0	b	C_0	π_1	π_2
15	20	40	1	10	139.249174	169.032544
32	60	40	1	10	370.221738	179.105075
45	80	40	1	10	393.249141	181.026621
15	20	80	1	10	643.479283	693.476989
32	60	80	1	10	1065.13429	703.54952
45	80	80	1	10	1103.50291	705.471065
15	20	60	1	10	346.919784	386.810322
32	60	60	1	10	673.233567	396.882853
45	80	60	1	10	703.93158	398.804399
15	20	60	1	10	346.919784	386.810322
32	60	60	1	10	673.233567	396.882853
45	80	60	1	20	693.93158	398.804399
45	50	60	1	20	138.405228	398.552247
30	50	80	1	20	848.568762	695.743444
0.8	1.2	6	0.5	0.2	5.303706	5.333558
1	1.5	10	0.7	0.3	12.65161	12.698663

TABLE IV. PROFIT VALUES OF FIRM 1 AND FIRM 2 AT VARIOUS INTEGRATION RATES

β_1	β_2	C_m	A	a_0	b	C_0	π_1	π_2
0.3333	0.0123	15	20	40	1	10	179.186	169.878
0.875	0.0058	32	60	40	1	10	374.137	181.523
0.7777	0.0041	45	80	40	1	10	410.536	184.246
0.3333	0.0208	15	20	80	1	10	717.016	696.706
0.875	0.0098	32	60	80	1	10	1070.85	712.249
0.7778	0.0069	45	80	80	1	10	1130.58	714.244
0.3333	0.0179	15	20	60	1	10	403.654	388.831
0.875	0.0084	32	60	60	1	10	677.974	402.351
0.7778	0.0060	45	80	60	1	10	726.037	404.712
0.3333	0.0179	15	20	60	1	10	403.654	388.831
0.875	0.0084	32	60	60	1	10	677.974	402.351
077778	0.0024	45	80	60	1	20	718.872	401.968
0.1111	0.0024	45	50	60	1	20	391.622	386.941
0.6667	0.0063	30	50	80	1	20	890.362	700.780
0.5	0.8345	0.8	1.2	6	0.5	0.2	5.6977	5.48943
0.5	0.5253	1	1.5	10	0.7	0.3	13.2372	13.2282

When both integrate IoT, the rate at which each integrate influences the profits. The higher the rate, the higher is the incentive and the higher is the profits. The firm with higher rate increases their profits considerably as the incentives increases. When the firms integrate IoT at close rates, the difference between the two profits decreases.

Furthermore, in the aim to help further-examine and understand our mathematical model behavior, plotting the function provides us with valuables insights. Essentially, visually clear representation of the function facilitates assessments, insight into parameter effects and supports decision-making. Fig. 1 and Fig. 2 presents the shape of the profit function plot of firm 1 and firm 2 respectively as well as their respective maximum profit related to β_1 and β_2.

Fig. 3 and Fig. 4 demonstrate that as the profit fluctuates towards the maximum, it stabilizes. As the integration rate increases, the profit increases up to the maximum point where it stabilizes.

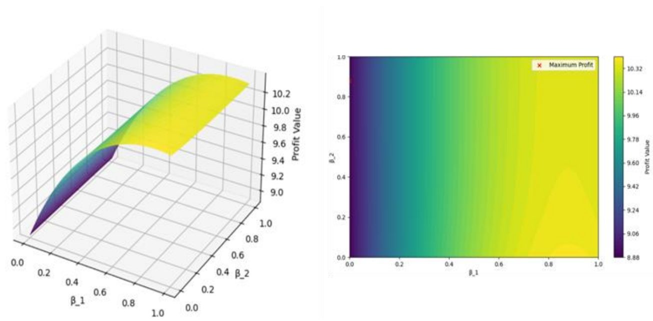

Fig. 3. Firm 1 profit visualisation.

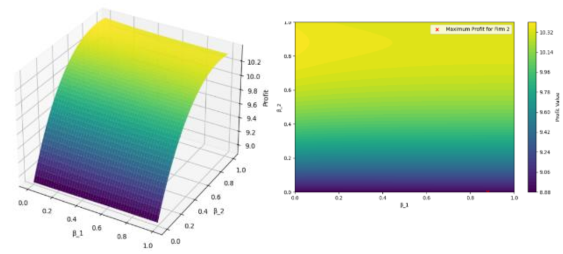

Fig. 4. Firm 2 profit visualization.

E. Discussion

In the previous section, we explored four different cases depending on the integration rate. Based on the analysis, the four different cases we analyzed can be considered as strategies for the 3PL firms. The first strategy is when no firm integrate IoT, the second strategy is when both firms choose to fully integrate IoT, the third strategy is when one firm integrates fully the IoT while the other firms doesn't integrate it and the last strategy is when both firms integrate IoT at different rates.

Depending on the incentive that the government offers and the costs engendered by the integration of IoT, the firms can choose the strategy where they integrate IoT in order to enhance their profit. In order to be competitive, the firm needs to integrate IoT at a greater rate than its competitive firm.

Parameters such as the incentive, the cost of IoT play an important role in the profit maximization. Maximizing the profits by Integrating IoT at higher rates is contingent upon the correlation between the incentives and the costs of integrating IoT. While the incentives get higher the profits increase. If the government doesn't help considerably with the integration, it is better to choose a strategy with lower IoT rates.

V. CONCLUSION

Globalization and the growth of e-commerce urged the logistics stakeholders to continuously strive for optimizing their operations. Logistics firms are experiencing significant pressure from customers, stakeholders and competitors to embrace digital transformation. The digitalization of the value chain has been the center of attention of both practitioner and researchers, investigating the ways to seize the opportunities from the I4.0 technologies. However, integrating these technologies is surrounded with several barriers and challenges.

Hence in this paper, we have studied the impact of integrating the IoT technologies in 3PL companies taking into consideration the high investment and maintenance costs that comes with integrating the technology. Using the Cournot duopoly model, we assessed the influence of integrating the IoT technology in the 3PL firm services on establishing competitive advantage. Our model studied the Cournot equilibrium based on the quantities of service offered by the 3PL firms in regards to the IoT integration rate. Our analysis has showed that integrating IoT can be added as a strategy set to enhance the competitiveness in the market of 3PL. Under certain conditions, integrating IoT can lead to higher profits. Both the government incentives and the IoT exploitation costs play a crucial role in determining the best strategy for the 3PL firms. Integrating IoT at considerably higher rates than the rival firm can bring an important competitive edge, whereas integrating it at closer rates can bring greater profits for both firms.

While this study has provided valuable insights into the understanding of the 3PL industry's response to technological disruptions, it is essential to acknowledge its limitations and the broader implications of our findings. Firstly, our analysis predominantly focused on the duopoly structure, which, although prevalent in many industries, may not fully capture the complexity of the 3PL sector. Future research should explore alternative market structures, such as oligopolies or monopolistic competition, to gain a more comprehensive understanding of the dynamics at play.

Secondly, our investigation primarily focused on economic and competitive factors namely the service level and technology adoption, overlooking the growing significance of sustainability and environmental concerns in modern business environments. The influence of sustainability practices in the supply chain management industry and in the 3PL sector precisely remains a critical avenue for future exploration. Integrating sustainability considerations into our model could provide a more holistic perspective on decision-making processes within the industry.

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