Applying Predator—Prey Model to Companies Practicing—Undergoing Dumping. Theoretical Basis and Empirical Notes

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Abstract— This article explores the potential application of predator-prey theory to understand and model the dynamics of commercially aggressive companies involved in persistent price dumping. Drawing inspiration from ecological systems, where predator-prey interactions govern population dynamics, we adapt the underlying concept to the business realm, specifically focusing on companies engaging in aggressive pricing strategies that negatively impact competitors. Through a formal model inspired by Lotka-Volterra differential equations, we aim to capture the intricate interplay between predatory companies (engaging in not sporadic dumping) and their prey counterparts (those impacted by it). The explorative article concentrates on industries where aggressive pricing strategies, such as dumping, play a pivotal role, i.e. in sectors like steel production, airline services, and e-commerce (alongside insights into industry-specific dynamics and competitive landscapes). It adopts a mixed-methods approach based on a critical analysis of both literature and industry evidence, providing a theoretical and operating model complete with a numerical simulation. The application demonstrates that the dynamic interactions between prey and predator result in oscillating cycles, i.e., a delicate equilibrium and associated fluctuations (depending on the characteristics and assumptions related to aggressiveness and resilience of the two species, the estimation of parameters and growth rates, the institutional response – authorities constraints, intervention, protection, etc.) that arise as prey and predators influence each other's populations in the shared ecosystem (market). The interdisciplinary nature of the issues provides valuable insights for policymakers, businesses managers, and industry stakeholders when navigating difficult competitive landscapes on the edge of (un)fair play and responsibility. Limitations and future directions of research are provided.

Keywords— Aggressive Pricing; Predator-Prey Models; Predatory Behaviors; Dumping; (Anti-)Competitive Strategies; Regulatory Interventions

I. Introduction

In the intricate landscape of corporate competition, predatory behaviors among companies assume diverse misconduct forms (predatory pricing or dumping, exclusionary tactics, product bundling, refusal to deal, predatory innovation, loyalty rebates, predatory hiring, M&As for monopoly power, predatory finance, misuse of standards setting, etc.) aimed at securing a competitive edge, harming rivals, or establishing market dominance in various ways (Easterbrook, 1981; Ganson & Wennmann, 2015; Schrepel, 2018; Peterson, 2006; Rikap & Lundvall, 2022; McCoy, 2005). While literature (Mesly et al., 2022) often frames predatory behavior in terms of economic concepts such as equilibrium, risks, and hidden societal costs, the dynamics of predator-prey relationships needed also to be explored where sellers specifically leverage group policies and benefits (internal synergies from business combinations) and information asymmetry to the detriment of competitors and/or clients. Within the broader scope of predatory behavior, predatory pricing is one prevalent tactic which extends beyond economic-legal considerations to encompass dynamic relationships. In fact, in the realm of economic strategies, the aggressive pricing approach commonly known as price dumping (Boltuck, 1987; Jones, 2015; Serences & Kozelova, 2021) has emerged as a complex phenomenon with far-reaching implications posing challenges to fair market competition. In the ever-evolving landscape of global commerce where competitive dynamics among businesses play a pivotal role in shaping market structures, indeed, dumping specifically involves the intentional sale of goods or services at prices lower than their production costs or market value, often as a strategic maneuver to unfairly steal a competitive edge (Porter, 2008). Such a practice introduces a predatory dynamic into the market, where certain entities act as predators, leveraging various tactics to exploit information asymmetry (or extract internal synergies generated within a business combination) and maximize their market share. In fact, once rivals retreat, the predatory firm can elevate prices to recover previous losses.

Regulatory bodies, both at national and international levels, have coped with the challenges posed by predatory pricing, primarily through Antitrust laws aimed at preventing anti-competitive behavior. The EU's approach, for instance, requires demonstrating a predatory strategy's likelihood to eliminate competition and subsequently raise prices for consumers. Nevertheless, the trade liberalization brought about by globalization, by stimulating strong international competition, has made it increasingly difficult for companies to successfully carry out predatory dumping.

Extensive literature has explored the complexities surrounding predatory practices, revealing a prevalence in overcoming entry barriers and their potential for short-term consumer benefits but long-term market distortions.

To comprehensively understand and analyze the intricacies of the dumping strategy and practice, for the first time we turn to the direct application of the theoretical framework Predator–Prey to gain further insights into the dynamics between aggressive companies ("predators") and their affected competitors ("prey").

Originating from ecological models (Lotka, 1925; Volterra, 1926), this powerful instrument shows potential to provide a conceptual and practical paradigm to re-examine in a suggestive and adequate manner the strategic interactions between entities employing aggressive pricing as a predatory tactic and the competitors / consumers who bear the economic consequences.

In more detail, this article delves into the application of the predator/prey theory to the context of dumping, exploring its dynamics, implications, and potential regulatory responses. Through this lens, we aim to shed light on the nuanced interplay between aggressive pricing strategies and their impact on market participants.

Aggressive pricing strategies, particularly those involving the deliberate reduction of prices to levels deemed unsustainable for competitors, have raised questions about fair competition and market equilibrium.

That said, the primary objectives of our research are as follows:

- Develop a conceptual framework inspired by predator-prey theory to model the interactions between commercially aggressive companies and their affected competitors in the context of price dumping.
- Propose and refine mathematical models based on Lotka-Volterra equations to represent the dynamics of aggressive pricing scenarios within industries.
- Explore real-world instances to validate and refine the proposed models, assessing their applicability to diverse industries.
- Consider the implications of the research findings for policymakers seeking to regulate and mitigate the impacts of aggressive pricing practices (fostering fair competition – in the presence of high aggressiveness and low resilience –, preventing monopolistic tendencies, and protecting the interests of consumers and competitors in the marketplace).

While the scope is broad, the model and analysis aim to provide insights that can be tailored to specific industries, considering the nuances inherent to each sector. In particular, the article adopts a mixed-methods approach based on a critical analysis of both literature and industry evidence, while the interdisciplinary nature of the issues provides valuable insights for policymakers, businesses managers, and industry stakeholders when navigating difficult competitive landscapes on the edge of fair play and responsibility.

The subsequent sections of this research article will delve into a comprehensive literature review, develop the mathematical model grounded in predator/prey theory, describe illustrative cases (also with numerical simulation), and discuss the implications of results. Limitations and future directions of research are provided. Through this exploration, we seek to contribute helpful insights into the understanding and regulation of aggressive pricing practices (namely dumping, in particular referring to persistent predatory, and not sporadic, dumping) in the contemporary business environments.

II. Literature Review

The economic literature on predatory behavior has been a subject of extensive research and debate. Predatory pricing (as special case of predatory behavior) occurs when a firm intentionally lowers its prices to a level below its costs with the strategic intent to harm or eliminate competitors. The classical economic view suggests that such borderline practices – oftentimes put in place to overcome barriers to entry (Pehrsson, 2009) and usually conducted as part of a broader group strategy through international or multinational development – can lead to short-term consumer benefits but may result in long-term market distortions and reduced innovation (Guiltinan & Gundlach, 1996; Kienzler & Kowalkowski, 2017).

Economic modeling has been early used to identify and describe predatory behavior – such as, for example, certain practices in the specific bus industry (Dodgson, 1993) –, but the difficulty in proving illegal predatory pricing practices made necessary a focus on the standards related to cost that courts typically apply (Ursic, 1994). In this perspective, scholars such as Areeda and Turner (1975) have emphasized the difficulty in distinguishing between aggressive price competition and genuine predatory pricing. In fact, the legal and economic thresholds for identifying predatory pricing remain contentious, with differing views on the necessity of proving recoupment and the actual ability of the predator to monopolize the market (Leslie, 2013).

In hindsight, the legality context in which questionable practices are experienced is especially relevant. Emblematic cases of jurisdictional relief, such as Brooke Group v. Brown & Williamson Tobacco Corp. in the United States, for example, have set standards for assessing predatory pricing claims (Thorson, 2021). However, the effectiveness of legal frameworks in addressing modern pricing strategies, especially in the digital age, remains a topic of ongoing discussion.

In this regard, while matching strategic theory and legal policy concerning the predatory pricing, Bolton, Brodley & Riordan (1999) suggested that predation would be more likely consequential to economic motivation, that is, subject to an efficiency's justification where below-cost pricing is necessary to achieve significant efficiency.

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Other scholars have pointed out how regulatory bodies, both at the national and international levels, have grappled with the challenges of such addressing predatory pricing, basically through Antitrust laws to prevent anti-competitive behavior (Hoekman & Mavroidis, 1996; Eken, 2020). For instance, the European Union's approach requires proving a predatory strategy's likelihood to eliminate competition and subsequently raise prices for consumers; and, more broadly, many countries have established a number of regulations to counteract the negative impacts of dumping (Du, 2022). These regulations have empowered authorities to impose additional duties or tariffs on dumped imports to level the playing field for domestic industries. Also, De Baere et al. (2021) reported how the WTO has specific provisions in the Agreement on Implementation of Article VI of the GATT that allow member countries to take anti-dumping measures (subject to certain conditions to ensure they are not used as a protectionist tool, in turn discouraged; Prusa, 2005).

Predatory pricing strategy (typical of international trade) is just an aspect of predatory behavior. In literature, the general conceptualization of predation is mainly associated with notions that are relevant to the economic domain, such as equilibrium, risks, and hidden societal costs (Mesly et al., 2022). Often the economic academics use the concept of predation differently, in several cases taking into consideration the dynamics of predator-prey relationships in individual interactions, where sellers assume the role of predators leveraging information asymmetry to their advantage, whereas the prey consist of unsuspecting (naïve) clients who suffer economic or financial harm as a consequence. In other cases, the prey are competitor companies. For example, Wang & Wang (2016) while exploring the recent competitive dynamics between TVs and smartphones, showed that Smart TVs and Android are playing the role of predators, while Flat panel TVs and iOS are playing the role of prey.

Wanting to summarize, the application of predator-prey models to economic phenomena, as inspired by ecological systems, has gained big traction in recent years. Lotka-Volterra differential equations (Lotka, 1925; Volterra, 1926), originally designed for biological populations, have found relevance in understanding interactions between economic entities (Wangersky, 1978) and modeling market competition dynamics (Marasco et al., 2016). In these approaches, market evolution is estimated and forecasted considering market shares as species competing for a common source: the market potential.

Research by Tsai (2017), among the others, explored the application of Lotka–Volterra models to industries demonstrating how predator-prey dynamics can offer insights into market behaviors. Such approaches have not always been set up to directly observe the magnitude or effects of price dynamics, as follows.

If Morris & Pratt (2003) and Parker (2010) have analyzed the Lotka–Volterra competition equations as a technological substitution model and knowledge spillovers and entrepreneurship, Von Arb (2003) has more specifically analyzed the predator prey models in competitive corporations' interrelationships within the stock market, while Gracia (2005) reviewed the business cycle to the Lotka-Volterra predator prey model. A peculiar application was advanced by Mehlum, Moene & Torvik (2003), by pointing out how in many developing and transition economies extortion and other forms of predation would lower profitability in private businesses and distort investment incentives. Instead, Reid et al. (2004) researched for a spatial distribution of predator/prey interactions with implications for measuring predator/fisheries overlap. More recently, Arabov et al. (2022) developed a modified mathematical model of the dynamics of the capital of a commercial bank. Moreover, Raghavendra & Veeresha (2023) analyzed the market for digital payments in India using the predator–prey mode, whereas Mesly et al. (2020) proposed market phases and predator–prey dynamics nested in economic cycles and consumer buying trends describing the peak and decline in the number of sellers and sold subprime mortgages.

Hence, the Lotka–Volterra model has found several applications in branches and sub-fields of economics like business administration (e.g., finance, and marketing) (Hung et al., 2017; Orbach, 2022; Kienzler & Kowalkowski, 2017). Their theory proves useful in portraying the dynamics of markets featuring multiple competitors, complementary platforms, and products, as well as those operating within a sharing economy, and beyond. Instances exist where a competitor may force others out of the market, while in some scenarios the market attains equilibrium allowing each firm to stabilize its market share. The L–V model is also able to capture situations involving cyclical changes in the industry or chaotic conditions marked by frequent and unpredictable shifts. Among a few examples, Huck et al. (2020) – providing a stylized model for disruptive and toxic economic behaviors in the context of predatory markets like those related to the subprime crisis of 2007-2009 – used and expanded on a predator-prey perspective that would endeavor to capture such rapacious and/or irrational behaviors more effectively within poisoned markets while showing that four market variables must be considered together over time (consumers, suppliers, toxic products and regulations).

Additionally, the predatory dynamics have been variously modeled in literature and applied to further economic scenarios, including pricing in business-to-business marketing contexts (Uslay, 2006). For example, the equilibrium of predator-prey networks has been linked to spatial price equilibrium, providing a foundation for the analysis of complex food webs (Nagurney & Nagurney, 2011).

That said, as noted above, the so-called price dumping is still a relevant phenomenon in the economy, widely known in the literature and business practice. This leads us to focus attention on a particular type of predatory behavior, potentially suitable to be framed in the theory in question (dumping). As known, the phenomenon occurs especially between corporations from developed countries and corporations from less developed countries (Chang & Raza, 2023). However, a gap exists in the literature as for the direct application of the predator/prey models to companies specifically engaging in aggressive pricing strategies such as price dumping. A similar (soft) case is exposed in Guidolin et al. (2019), where competition and forecasting are examined comparing regular to promotional sales in new product life cycles. The study performs a joint analysis of regular (full price) and promotional (discounted price) sales of a product, on the hypothesis that the two sale processes can influence each other. This stimulates us to focus on particularly aggressive pricing strategies practiced to the detriment of other economic agents (not only customers, but also competitors), exploring the appropriateness of applying the L–V theory.

To conclude, analogies between ecological ecosystems and economic systems have been drawn in various studies. Just as predators influence the behavior of prey populations in ecological systems, economically dominant firms can shape the strategies and survival of competitors, and they can predate through price dumping, with significant impact on the market. Research by Baumol and Oates (1988) introduced the concept of "unstable equilibrium" in economic ecosystems, highlighting how competitive advantages could lead to self-reinforcing cycles of market dominance (Becker & Leopold-Wildburger, 2020; Zakuan & Jacob, 2021). This concept sets the stage for considering how predator-prey models might offer valuable insights into understanding the dynamics of aggressive pricing practices in industries.

In summary, the literature highlights the ongoing discourse surrounding predatory pricing in economic literature, the challenges faced by regulatory bodies in addressing such practices, and the emerging applications of predator-prey models in understanding economic interactions. However, a gap remains. This research aims to bridge a gap in applying predator/prey models directly to commercially aggressive companies engaged in price dumping by developing and refining a formal model inspired by the L–V theory, offering a novel perspective on the complex dynamics of aggressive pricing in contemporary markets.

III. Modeling dumping effect within the economic predator–prey theory

The Lotka–Volterra conceptual framework (so called *Predator–Prey Theory*), as known, consists of a set of equations to study an expansive ecosystem where prey and predators coexist. The prey, symbolized as P (for example, gazelles), encompasses a population that thrives through intrinsic reproductive abilities (r_P). The predators, represented by D (for examples, lions), impose a natural check on the prey population (a_{PD}) as they engage in hunting. Conversely, the predators rely on the availability of prey (b_{DP}) for sustenance. The model describes a decline in the predator population (r_D) occurring when hunting becomes challenging, while an increase is witnessed when prey is plentiful. Lotka and Volterra proved that these dynamic interactions between prey and predators result in oscillating cycles. In brief, the prey population expands when predators are scarce, only to decline when predation intensifies. Simultaneously, the predator population rises when there is an abundance of prey, but it declines when resources become scarce. This succinct narrative provides an exploration of predator-prey dynamics, portraying the delicate equilibrium and cyclical fluctuations that arise as prey and predators influence each other's populations in a shared ecosystem.

It has been mentioned that the model in question has been applied to describe certain economic dynamics (especially in the fields of finance, organization, and marketing). As a consequence, the predatory behavior of certain companies especially in foreign markets may be suitable to be modeled according to L–V theory. Therefore, building upon the ecological inspiration of predator-prey dynamics, we propose a mathematical model grounded in Lotka–Volterra equations to represent – under the above-mentioned biological metaphor – the interactions between commercially aggressive companies ("predators") and their affected competitors ("prey"). The model aims to capture the essential dynamics of dumping practices within industries, the market share shifts, the competitive pressures, and the impact of aggressive pricing on the overall market structure.

Let us model the Prey Dynamics ('aggressed' Competitors) vs Predator Dynamics (Aggressive Companies), as follows.

The population dynamics of the competitor companies (P) affected by aggressive pricing can be described by the following differential equation:

$$dP/dt = r_P P - a_{PD} PD/M$$

where:

- P: Population of competing companies (Competitors).
- D: Population of the aggressive pricing company (Predator).
- r_P: Intrinsic growth rate of the competitors.
- a_{PD}: Coefficient representing the negative impact of aggressive pricing on competitors.
- M: Carrying capacity, a limiting factor for population growth.

This equation reflects the natural growth of the competitor population ($r_P P$) and the negative impact ($-a_{PD} PD/M$) of the predator's aggressive pricing.

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At the same time, the population dynamics of the commercially aggressive companies (D) engaging in aggressive pricing are represented by the following differential equation:

$$dD/dt = -r_D D + b_{DP} PD/N$$

where:

- D: Population of the aggressive pricing company (Predator).
- P: Population of competing companies.
- r_D: Intrinsic decline rate of the aggressive pricing company.
- b_{DP}: Coefficient representing the positive impact of aggressive pricing on its own population.
- N: Carrying capacity for the aggressive pricing company.

This equation accounts for the natural decline of the aggressive companies ($-r_D D$) and the positive impact ($b_{DP}PD/N$) of their aggressive pricing on their own population.

The following diagram (Fig. 1) under these equations system (where dP/dt and dD/dt represent the instantaneous growth rates of the two populations, and t represents time) – known as "predator-prey graph" – illustrates the population dynamics between predators and prey typically depicting how the populations of these two species change over time.

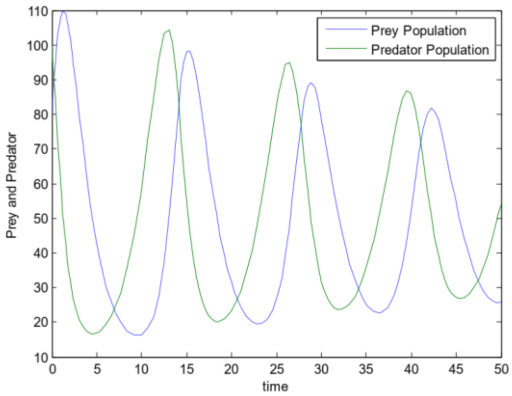

Fig. 1 Example of Population Dynamics of Predator and Prey

The dynamics are typically characterized by cycles of rise and fall in population sizes. As the prey population (aggressed competitors) increases, the predator population (the commercial aggressive companies) follows suit due to the availability of more resources. However, as the predator population grows, it puts increased pressure on the prey population, causing it to decline. This, in turn, leads to a decrease in the resource supply for predators, resulting in a decline in their population. The cycle then repeats, creating oscillations in the population sizes of both species.

Another diagram (Fig. 2) depicts the phase-space plot for the predator prey model.

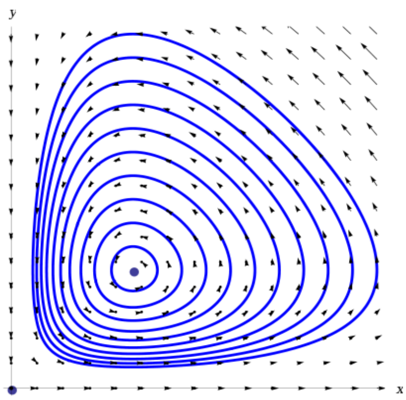

Fig. 2 Phase-space plot for the predator prey problem for various initial conditions of the predator population

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(*y* axis: D - dumpers; *x* axis: P - prey).

The diagram describes the problem for various initial conditions of the predator population, by plotting solutions parametrically as orbits in phase space, without representing time (with one axis representing the number of prey and the other axis representing the densities of predators for all times). This corresponds to eliminating time from the two differential equations above to produce a single differential equation:

$$dD/dP = -(D/P)[(r_{DP} - b_{DP})/(a_{PD}D - r_P]$$

By integrating it we draw a value V, that is a constant quantity depending on the initial conditions and conserved on each curve.

$$V = r_D P - b_{DP}\ ln(P) + a_{PD}D - r_P\ ln(D)$$

In such a framework, on the one hand, the "orbital structures" (typical of the dynamical systems theory) refer to the trajectories followed by the predator and prey populations over time (these trajectories depict the dynamic interactions between the predator and prey). On the other hand, the "level curves" of the function H represent lines on a graph connecting points with the same Hamiltonian value in a conservative system. In the context of the Lotka–Volterra model, the Hamiltonian function H typically represents the total energy in the system. These level curves illustrate regions of the phase space where the system exhibits similar energy levels, providing insights into the stable states and dynamics of the predator-prey interactions.

To ensure the accuracy and relevance of this model, we can employ sensitivity analysis and parameter estimation techniques.

First, sensitivity analysis involves systematically varying the model's parameters to observe the effects on the system's behavior. In our context, we focus on the sensitivity of the model to changes in the coefficients a_{PD} and b_{DP}.

We can systematically adjust a_{PD} within a plausible range to observe its impact on the population dynamics of competitors (P) and aggressive companies (D). This analysis helps identify the range of a_{PD} values that lead to significant shifts in the model's outcomes.

Similarly, b_{DP} represents the positive impact of aggressive pricing on the aggressive company's population. Sensitivity analysis involves varying b_{DP} to assess its influence on the model's predictions. Identifying the range of values that significantly affect the system allows us to understand the dynamics of how aggressive pricing strategies impact the aggressive companies themselves.

Second, parameter estimation is the process of determining the values of coefficients (a_{PD} and b_{DP}) that best align the model with observed data or real-world insights. This step ensures that the model accurately reflects the dynamics of aggressive pricing practices within industries.

We can utilize historical industry data (or inferential statistics), case studies, and expert insights to inform the estimation of a_{PD} and b_{DP}. By comparing model predictions with actual industry behaviors, we are allowed to refine the coefficients to enhance the model's predictive power.

Alternatively, statistical techniques, such as regression analysis, may be employed to estimate the coefficients based on empirical data. These techniques help quantify the relationship between the model's parameters and observed outcomes, facilitating a more robust calibration of the predator-prey model.

It is worth noting that sensitivity analysis and parameter estimation are iterative processes. The initial estimates are refined based on insights gained from sensitivity analysis, and the process is repeated until the model consistently aligns with observed behaviors. This iterative refinement ensures that the predator-prey model accurately captures the nuanced dynamics of aggressive pricing practices within industries.

IV. Industry Cases and Numerical Simulation Results

This section provides examples referring to companies accused of engaging in aggressive pricing practices and the subsequent impacts on market dynamics (especially at the international level). By analyzing these real-world examples, we aim to check the fit of the Lotka–Volterra predator–prey model.

Real-world examples of corporations engaged in aggressive pricing practices or dumping are numerous. It is important to note that accusations of predatory pricing or dumping can be subject to legal and regulatory interpretation, and not all cases lead to proven wrongdoing. Examples:

Dumping in the Steel Industry. Especially in the past, there have been allegations of dumping in the steel industry, where some countries accused others of exporting steel at prices below production costs. This led to trade disputes and the imposition of anti-dumping duties.

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Technology Sector Price Wars. The technology sector has witnessed aggressive pricing strategies, where companies reduce the prices of their products or services to gain a competitive edge. One notable case was the price war among smartphone manufacturers, with accusations of companies selling below cost to gain market share.

Airline Industry Fare Wars. Airlines have engaged in fare wars with prices dramatically reduced to attract passengers. While this can be a legitimate strategy to fill seats, accusations of predatory pricing arise when airlines are accused of driving competitors out of specific routes or markets.

Dumping of Agricultural Products. Agricultural products, such as grains or fruits, have been subject to accusations of dumping. Countries or regions accused of dumping these products might flood international markets with their produce, potentially harming local farmers in importing countries.

E-commerce Sector Price Wars. Price wars among e-commerce giants are common, with companies offering significant discounts and promotions to attract customers. Accusations of predatory pricing may arise if a company is accused of intentionally selling products at a loss to eliminate competitors.

Pharmaceutical Industry. In the pharmaceutical industry, there have been instances with companies suspected of predatory pricing by significantly lowering the prices of certain drugs, making it difficult for competitors to compete and potentially leading to market dominance.

It is important to underline that the perception of predatory pricing or dumping can vary, and legal actions are often taken to investigate and address these allegations.

By applying the Lotka–Volterra model, we would have, for example:

Steel Industry Dumping:

- Predator (Dumping Company): Company accused of selling steel below cost.
- Prey (Competitors): Other steel manufacturers.

Airline Industry Fare Wars:

- Predator: Airline engaging in aggressive pricing.
- Prey: Other airlines on specific routes.

E-commerce Price Wars:

- Predator: Company engaging in aggressive pricing.
- Prey: Competing e-commerce companies.

We consider the first case in order to provide a numerical example (related to the steel industry dumping). In the steel industry case, we consider a competitive scenario involving the new entrant Company alpha as the aggressive pricing entity engaging in price dumping and the existent competitors represented by Company beta, Company gamma, and Company delta.

Let us assign numerical values to the parameters employed in the mathematical model. The values assigned in this numerical simulation are instrumental in describing the L–V model and determining its results and consequent suggestions. In particular, in order to determine the market shares attributable to competitors in the analyzed sector, the averages of historical industrial production values of the last three years are taken into account (tons of steel), as well as the forecast business plans from which the growth rates of production are derived (the negative and positive impact factors per year are assumed based on the specific dynamics of the steel industry examined and the expected influence of dumping strategies, taking into account the coefficients inferable from comparable evidence and international practices or similar cases):

- Intrinsic growth rate of competitors (r_P): 0.02 per year.
- Coefficient representing the negative impact of aggressive pricing on competitors (a_{PD}): 0.001 per year.
- Carrying capacity for competitors (M): 500,000 tons.
- Intrinsic decline rate of the aggressive pricing company (r_D): 0.01 per year.
- Coefficient representing the positive impact of aggressive pricing on its own production (b_{DP}): 0.002 per year.
- Carrying capacity for the aggressive pricing company (N): 200,000 tons.

Let us simulate the model for a period of 10 years and observe the production dynamics of the steel companies:

- Initial production of competitors (P_0) undergoing dumping: 300,000 tons (assumed relatively moderate).

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- Initial production of aggressive pricing company (D_0) practicing dumping: 100,000 tons (assumed relatively high).

The differential equations are as follows:

$$dP/dt = 0.02P - 0.001PD/500{,}000$$

$$dD/dt = -0.01D + 0.002PD/200{,}000$$

Using numerical methods (e.g., Euler's method), we can compute the production of populations over time. The results might indicate how the aggressive pricing strategy influences the market shares of the steel companies over the 10-year period.

Year 1:

- P=308,700 tons
- D=100,600 tons

Year 5:

- P=315,500 tons
- D=98,200 tons

Year 10:

- P=322,800 tons
- D=96,100 tons

Interpreting the results coming from the model, the simulation suggests us that, over time, the aggressive pricing strategy implemented by Company alpha affects both its competitors (beta, gamma, delta) and itself. The model provides insights into how the populations of competing companies and the aggressive pricing company dynamically interact within the steel industry. In our case, the companies engaging in dumping (D)'s increasing their aggressive pricing practices will negatively affects their own population due to potential regulatory interventions, market saturation, or other limiting factors. This leads to a potential decrease in D over time. Simultaneously, the competing companies (P) adapt to the changing market conditions. They may increase in population as they respond strategically to the challenges posed by the companies practicing dumping. Such increase could result from innovations, market diversification, or other competitive strategies. On the contrary (opposite scenario), it could be the case that the starting positions (and expected growth rates) are reversed in the two populations, and that the dumping firms (D) intensify aggressive pricing practices, potentially benefiting from reduced regulatory constraints or increased market dominance strategies; as a consequence, the intensified dumping practices will continue, resulting in a further increase in the population of companies engaging in dumping, whereas the competing firms (P) will find it difficult to adapt to aggressive pricing, leading to a decrease in their population (production).

Similar simulations can be run for other industries (variables: specific production volumes – as food commodities, drugs and vaccines, etc., turnover, number of flights, number of competitors, number of platforms, startups, patents, etc.). In any case, important considerations are necessary:

- Model limitations: the Lotka–Volterra model, as a pattern, is a simplification and may not capture all aspects of complex economic interactions.
- Parameter interpretation: coefficients like aPD and bDP need careful interpretation in economic terms.
- Assumptions: the model assumes instantaneous responses to changes in population sizes and may not account for delays or additional strategic planning.
- Dynamic nature: since economic agents and entire systems itself are dynamic, parameters may change over time (due to market conditions, regulations, or other factors). This may partially invalidate the specific model suitability.

In more detail, the application of the predator-prey model yields key findings across industries, due to the industry-specific dynamics. The steel industry exhibited resilience among competitors, the airline sector showcased the potential for rapid shifts in market shares, and the e-commerce landscape reflected the influence of scale on aggressive pricing strategies. In general, sensitivity analysis reveals the significance of coefficients aPD and bDP in influencing model outcomes. Small variations in these coefficients demonstrated substantial impacts on the dynamics of competitors and aggressive companies. One solution could be running a scenario analysis by dividing predator aggressiveness and prey resilience, respectively, into three grades (high, medium, low), and recomposing the results by making a synthesis of the best, medium, and worst cases by assumed probability rates of occurrence.

In the light of the above analysis, while the direct application of Lotka–Volterra equations to economic scenarios show several limitations, the present adaptation provides a conceptual framework for understanding the basic dynamics of predatory pricing

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in various industries. Additionally, empirical validation and parameter estimation are undoubtedly useful to provide a more accurate representation of specific industry cases.

The implications of applying the predator-prey model to aggressive pricing commercial strategy and dumping behaviors are multifaceted and extend to both academic understanding and practical applications. By gaining insights into the dynamics of competitive interactions, this study can stimulate valuable reflections, speculations, and suggestions on business administration, by contributing meaningful perspectives to policymakers, industry stakeholders, and researchers.

Besides, understanding the dynamics of aggressive pricing practices provides a basis for formulating effective regulatory interventions. In fact, the predator-prey model allows policymakers to assess the potential impact of regulatory measures on industry dynamics, helping to strike a balance between fostering competition and preventing anti-competitive behaviors. In other terms, insights derived from the model can inform the design of regulations that mitigate the negative consequences of aggressive pricing without stifling legitimate competition.

The predator-prey model also can offer a lens through which to examine the role of consumer behavior in shaping market dynamics. By incorporating factors such as consumer preferences, price sensitivity, and brand loyalty, future iterations of the model can provide a more comprehensive understanding of how consumers influence the success or failure of aggressive pricing strategies. This insight is valuable for companies seeking to align their strategies with consumer expectations and preferences.

Moreover, businesses can leverage the research findings to inform strategic decision-making in the face of aggressive pricing competition, highlighting opportunities and risks. The model provides a tool for anticipating the potential consequences of adopting aggressive pricing strategies and allows companies to refine their approaches based on predicted outcomes. In addition, understanding the dynamics of competition through the predator-prey lens enables companies to develop more resilient and adaptive business strategies.

Definitely, while this research lays the foundation for applying predator-prey models to aggressive pricing management related to dumping practice, there are several avenues for future exploration:

- Dynamic Parameters: Introduce dynamic parameters to account for changing market conditions, consumer preferences, and external factors. Dynamic modeling allows for a more realistic representation of the evolving nature of aggressive pricing dynamics.
- Industry-Specific Models: Tailor the predator-prey model to specific industries, recognizing that the dynamics of aggressive pricing can vary significantly between sectors. Industry-specific models can provide more nuanced insights and better guide regulatory and business strategies.
- Multi-Agent Modeling: Explore multi-agent modeling approaches to capture the interactions among multiple aggressive companies and their competitors simultaneously. This approach can offer a more comprehensive representation of complex competitive landscapes.
- Experimental Validation: Conduct massive experimental validations using controlled environments or simulated markets to test the model’s predictions against real-world behaviors. Experimental validation enhances the model's reliability and applicability.

Last but not least, dumping, i.e. the practice of selling goods below cost in foreign markets, raises ethical concerns. It creates unfair competition, jeopardizes local jobs, and fosters economic dependency. Environmental and social impacts may emerge as companies cut costs, compromising standards. Besides, dumping distorts market dynamics, hindering fair competition and potentially eroding innovation, whereas prolonged practices contribute to trade imbalances. The consideration of the greater responsibility of modern companies may weaken the aggressiveness and impact on the parameters, even to the point of invalidating the model.

V. Conclusion

This research has undertaken an exploration of the application of predator-prey models to aggressive pricing scenarios within industries. By drawing inspiration from ecological systems, specifically Lotka–Volterra equations, we developed a mathematical model to capture the dynamics between commercially aggressive companies ("predators") and their affected competitors ("prey"). Examples in the steel industry, airline sector, e-commerce landscape, etc., prove that such a model can be tested and refined the model, since it is able to provide interesting insights into the complex interactions that characterize aggressive pricing strategy and practice.

For businesses management, the model provides a strategic tool for anticipating the consequences of aggressive pricing strategies. By understanding the dynamics of competition through the predator-prey lens, companies can navigate competitive landscapes more effectively and make informed strategic decisions.

However, it is crucial to acknowledge certain limitations. First, the model makes simplifying assumptions to represent complex economic interactions. Real-world conditions may involve additional factors that influence aggressive pricing practices. Second, the economic landscapes are dynamic, whereas the model's predictions are based on specific timeframes. Changes in market conditions, consumer behaviors, or regulatory environments could influence the model's accuracy over time.

Future research can build upon this foundation by exploring dynamic parameters, industry-specific nuances, multi-agent modeling, and experimental validations. These directions would refine the model's sophistication and broaden its applicability to diverse competitive scenarios.

In conclusion, the application of predator-prey models to dumping strategies offers a promising avenue for advancing our understanding of economic interactions. The interdisciplinary nature of this research opens avenues for collaboration between economists, regulators, managers, and industry practitioners. As industries continue to evolve, the framework provides a foundation for navigating the intricate dynamics of aggressive pricing, contributing to the ongoing discourse on strategy setting, responsible management, fair competition, and market equilibrium.

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