Presented at the DLSU Research Congress 2016
De La Salle University, Manila, Philippines
March 7-9, 2016

Modelling individual decision making in a post-apocalyptic, dystopic economy using a Player–versus–Environment stochastic game: a theoretic discussion

Edgardo Manuel Jopson*
[1] *De La Salle University*
School of Economics
**Corresponding author: manuel.jopson@gmail.com*

Abstract: In a post-apocalyptic dystopia, individuals struggle to survive is more pronounced than the usual. From the risk of death ever present given the level of violence and cruel environment caused by catastrophic events, an individual experiences a player–versus–environment (PvE) game that gambles its life in order to gather resources for survival. This paper attempts to express the player's possible strategies in order to survive these conditions, which would largely depend on risk propensities and survival. We propose that the player's survival would depend on his or her demand for resources, governed by an Epstein-Zin Utility function, which incorporates risk and consumption preferences and the players adaptability is accounted for by a dynamic Cobb-Douglas production function which takes into consideration the ability and survival skills via a multiplier which changes after the second stage of the game in order to account for the player's learning curve.

Key Words: game theory; dystopia; player–versus-environment survival analysis; dynamic stochastic games

1. Introduction

From the seminal work of von Neumann and Morgenstern (1944), the application of game theory in economics has been essential in order to express fundamental concepts such as competition, cooperation and strategy, shaping our already expansive literature on the field. Although mathematical economics is still on its adolescence; "at an earlier stage of its evolution" according to von Neumann and Morgenstern; that was seventy–two years ago and a great deal of progress in the field have already been made since then which still pales in comparison to the works produced in the field of physics, advancements in the twentieth century have transcended the boundaries of economics into the science that we know today. Examples of these leaps in the application of advanced mathematics to the field of economics include stochastic games (Shapley, 1953), dynamic non-cooperative game theory (Basar & Olsderm, 1995), and dynamic stochastic general equilibrium (Gali, 2008) (DeJong, 2007), among many others.

The most notable use of strategic game theory would be in the theory of the firm, which heavily applies the Nash equilibrium in order to explain competitive firm's behavior. In a greater extent, the behavior of oligopolies has been highlighted, and has become essential topics discussed in undergraduate and graduate classes in Microeconomics. In retrospect, game theory has already dominated the field of microeconomics in such an extent that it has been an essential element in understanding the field.

However, competitive games are not only limited to firm behavior, but consumer behavior as well. In an imperfect market, individuals would demand for goods that the market cannot accommodate[1]. This is where game theory comes in; strategies can be laid to explain the strategy that the individual takes based on different payoffs and probabilities. Now, adding the fact that individuals do not behave statically, we create a dynamic game which is closer in line with reality. Create a certain level of randomness that involves different states–of–the-world, and then we have ourselves a dynamic and stochastic game which we hypothesize to be the key to unlocking the essence of survival.

The pursuit of economic stability has always been in the mindset of humanity; that is, we are more inclined to prefer average outcomes whatever the state–of–the–world may be, over extremes. Humanity also prefers to have stable relationships amongst each other and devotes a great deal of resources to do so; institutions such as the United Nations, the World Bank, the World Health Organization, the World Trade Organization, etc. which ensures that humanity does not stray to the path of self-destruction, by insuring sustainable development, combating terrorism, promoting gender equality, securing food production. Overall, these institutions are in place in order to maintain peace and security amongst member nations (United Nations, 2016).

However the world not ridden of the threat of terrorism, biological epidemics and natural disasters; in the twenty-first century alone, the number of armed assaults has more than doubled from ten years ago, as well as for bombings and explosive terrorism. Not only have their incidences doubled, but their rate of success as well. From the beginning of the twenty-first century up to 2014, terrorist attacks have become 500% more successful.

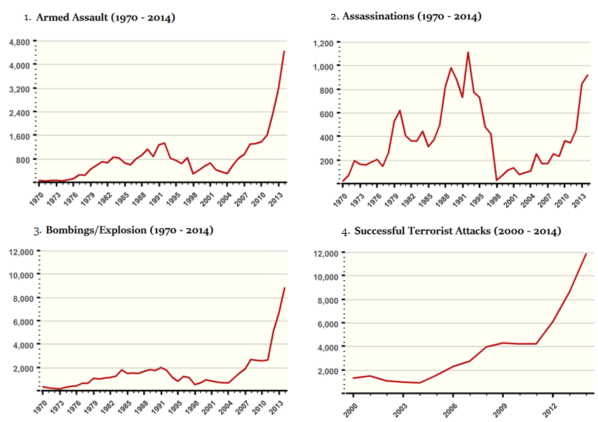

Fig 1. Incidence of armed assaults, assassinations, bombings/explosions and successful terrorist attacks (Source: START, Global Terrorism Database)

Aside from the threat of widespread terrorism and violence, some scholars are taking the problem of uncontrolled, rapid development in technology as a legitimate threat to humanity's survival. In the situation of a technological fallout, the concept of the singularity and Moore's Law has been a major topic for academic debate. In short, Moore's law states that the computational power of transistors in a computer doubles every 18 months – which translates that computers have an exponential growth in terms of intelligence, while humans do not. Futurists such as Ray Kurzweil predict that humans will be dependent on machines in the middle of the twenty-first century (Diamandis & Kotler, 2012)

[1] Take the market for expensive smartphones as an example. The market of iPhones in the Philippines creates an uneven demand for the phone–even those who do not have the means to actually buy the phone demand to have it. Hence some resort to theft, unnecessary debt and fixed–network options that render the buyer tied to the network provider. These are not necessarily bad (with the exception of theft, of course), but these behaviors usually create a more distorted market – a market that cannot be fully explained with the perfectly competitive, conventional economic laws of supply and demand can.

(Chalmers, D., 2010), the question of stopping these unregulated computers to decide to take control would be raised. Despite this statement sounding rather in the realm of science-fiction, computer scientists and physicists are considering this far from a myth, but rather an impending doom for humanity: in the likes of Stephen Hawking, Elon Musk, and Vernor Vinge (Luckerson, 2014).

Given characteristics of the agents interacting in a post apocalypse we explain how a typical player would behave given the chaotic environment where the risk changes over time at random using game theory.

2. METHODOLOGY

This paper utilizes the formal modelling approach of mathematical economics, specifically in game theory in a dynamic and stochastic setup.

3. THEORETICAL FRAMEWORK

This paper attempts to model the behavior of the individual that endeavors to survive the dystopic landscape set using game theory. In this model we assume that our representative player, *Player A*, is mobile and makes decisions to consume resources (optimize survival) and invest in capital (gather food and resources). The risk of death is denoted by σ and the intertemporal elasticity of consumption denoted by ρ .[2] Thus

$$\underset{Player\ A}{S(z)} = \max_{Z}\left\{ z(c_{optimal,}k,\tau,\Omega)^{\alpha} + \beta\left[E[S'(z)^{1-\sigma}]^{\frac{1}{\alpha(1-\sigma)}} \right] \right\}^{\alpha} \quad \text{(Eq.1)}$$

where

$$z = f(c^{*},k,\tau,\Omega), \quad \alpha = \frac{1}{1-\rho}$$

$S(z)$ denotes the survivability function of the individual as he or she traverses the dystopian post-apocalyptic world. which is a function of consumption c^{*} at the optimal consumption in terms of calorie intake, investment in capital resources k, the "will to survive" denoted by τ and investment of the individual in developing strength, agility and mental alertness in order to effectively survive the dystopic landscape denoted by Ω. Keeping in mind that the game environment is a harsh dystopia; filled with other competitors which impose a risk to *Player A.*

The player is responsible for allocating his labor hours and leisure depending on the risks involved in production. Since we are situated in a dystopic economy (hence, a diseconomy[3]), assume a constant threat of death while gathering resources, hence leisure does not exists. Rather, the player will be sheltering herself, minimizing the risk of death; denoted as *hide*, while labor is denoted as *seek*. When the player chooses to seek resources, she is able to accumulate resources enough for her to live for another time period, called a *stockpile*. Given these assumptions, we model a dynamic Cobb-Douglas production function:

$$A(q) = E\sum_{t=1}^{\infty}[L(w,r)^{\beta}{}_{t}K(w,r)^{1-\beta}{}_{t}\Omega_{t}\Lambda_{t}] \quad \text{(Eq.2)}$$

In this adaptation function, we denote $A(q)$ as our adaptability function where it is a function of Labor and Capital, allocated within a Constant Elasticity of Substitution, a multiplier Ω_t and Λ_t

---

[2] σ denotes the Arrow-Pratt relative risk aversion coefficient and ρ denotes the IES (Krusell, 2014)

[3] In the situation of a dystopia, we assume that the market is nonexistent, which goes without saying that law and order is also nonexistent. If one can imagine the film *Book of Eli* (Hughes & Hughes, 2010), trade is done via a common commodity, such as water, or in the form of barter. The important element that has to be considered in this type of economy is that there is no government that enforces the law. This means that the players in this model are self-reliant and are responsible for their own survival.

denoted for the abilities and an independent force of mortality, respectively.

$$w = f[\zeta_t, p] \qquad \text{(Eq.3)}$$

$$r = f[\zeta_t, p] \qquad \text{(Eq.4)}$$

$$\Omega_t = \sum_{t=1}^{\infty} \beta^t f(\omega_t, A_{n_{t-1}}(q), E_t) + \varepsilon_t \qquad \text{(Eq.5)}$$

$$\Lambda_t = \frac{f(t)}{1-F(t)} \bullet f(1-\zeta_t) \bullet E_t \qquad \text{(Eq.6)}$$

In equations 3 to 6, ζ_t denotes the action "Seek" for period *t* while η_t denotes the action "Hide", also for period *t*. Furthermore, we set wages and rent as a function of the action "Seek" which allows our player to "purchase" output, and prices, *p*, which denotes the resource cost for gathering resources. Ω_t is a function of a learning curve which is affected by the previous period's adaptability function multiplied by a learning curve multiplier discounted over time, and the game *Environment* denoted by E_t. Since ability is an estimate, we take into account an error term, else the player's learning varied from the true estimate. Λ_t is the force of mortality that takes into consideration the probability of death (Konstantopoulos, 2006). If at that specific period the player dies, *A*(*q*) then approaches zero, terminating the game. A component of some function involving the "Hide" option is made, as well as the *Environment* of the game.

Note that *Player A* is now playing a game of survival against a new *environment. An environment* E_t for this study is not only limited within the forces of nature, but a collection of natural hazards $(e_k)_{k=1,\dots,m}$ and optimizing agents $(b_l)_{l=1,\dots,n}$ such that

$$e_k = P(e_k)d(e_k) \qquad \text{(Eq. 7)}$$

$$b_l = P(b_l) f\left[S_{b_l}(z), A_{b_l}(q), \Lambda\right] \qquad \text{(Eq. 8)}$$

$P(e_k)$ denotes the probability of event e_k and $d(e_k)$ denotes the disutility caused by the event, such that $0 \le P(e_k) \le 1$ and $d(e_k) \le 0$. Furthermore, $P(b_l)$ denotes the probability of *Player A* of encountering b_l and $f\left[S_{b_l}(z), A_{b_l}(q), \Lambda\right]$ which is optimizing choice of b_l which will affect the chance of survival[4] for *Player A*.

Without loss of generality, let *m* = 2 denoting two natural events, and *n* = 2 where there are only two players, *Player A* and *Player B* and both players have the same functional form for survival and adaptation, and they are both experiencing the same environment. Illustrating their respective survival strategy using a decision tree for two periods and *n* periods

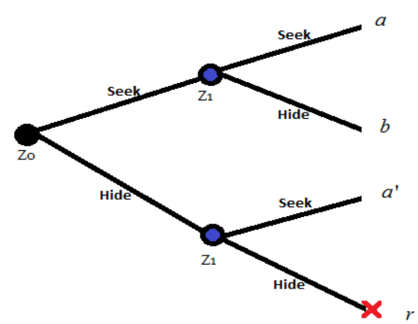

Fig. 2. Hide and Seek Decision Tree (2 stage) (von Auer, 1998)

Extending *n* up to the zth stage

[4] It must be proven that $f\left[S_{b_l}(z), A_{b_l}(q), \Lambda\right]$ is strictly negative in order to show that the effect of a more "dangerous" competitor increases the risk of gathering resources.

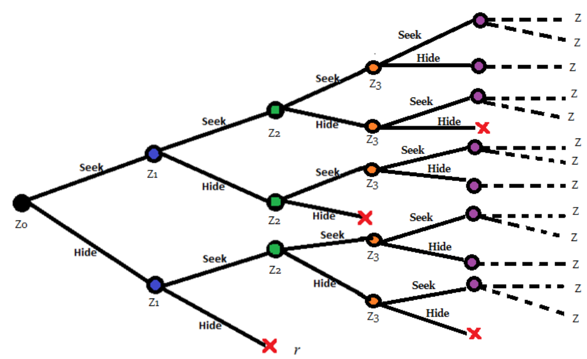

Fig. 3. Hide and Seek Decision Tree (n stage) (von Auer, 1998)

With the given illustration, we can formally define the set of strategies available for both players as such with their respective payoffs

For a two stage game

$$[\zeta,\zeta]=a, \quad [\eta,\eta]=r\rightarrow\varphi$$
$$[\eta,\zeta]=b$$
$$[\zeta,\eta]=a'$$

For a three stage game

$$[\zeta,\zeta,\zeta]=a, \quad [\zeta,\eta,\eta]=r\rightarrow\varphi$$
$$[\zeta,\zeta,\eta]=b, \quad [\eta,\eta,\zeta]=r\rightarrow\varphi$$
$$[\zeta,\eta,\zeta]=c, \quad [\eta,\eta,\eta]=r\rightarrow\varphi$$
$$[\eta,\zeta,\zeta]=a'$$
$$[\eta,\zeta,\eta]=b'$$

Where $\varphi = \{U[\eta, \eta]\} = 0$ when the player chooses a hide-hide strategy at any stage of the game.

In the case of a z stage game, there are $f^{(z)}$ variations of choices from the initial choice made at the first stage, where z denotes the number of time periods and f is some payoff. Note that for an agent l who decided a $[\eta,\eta]$ strategy, immediately that agent perishes on or before the end z stage.

4. ACKNOWLEDGEMENTS

The author acknowledges insightful suggestions by Dr. Jesus Dumagan, Dr. Marites Tiongco, Dr. Angelo Unite, Dr. Mariel Sauler, Dr. Gerardo Largoza, Ms. Sharon Mapa and Mr. Luisito Abueg from the Brown Bag presentation held on the 27th of January, 2016.

5. REFERENCES

Besanko, D. A., & Braetigam, R. R. (2011). *Microeconomics.* New Jersey: John Wiley & Sons, Inc.

Chalmers, D. (2010). The Singularity: A Philosophical Analysis. *Journal of Consciousness Studies*, 7-65.

DeJong, D. (2007). *Structural Macroeconometrics.* Princeton University Press.

Diamandis, P., & Kotler, S. (2012). *Abundance: The Future is Better than You Think.* New York: Simon and Schuster, Inc.

Epstein, R. (2009). *The Theory of Gambling and Statistical Logic.* London: Elsevier, Inc.

Gali, J. (2008). *Monetary Policy, Inflation and the Business Cycle.* Princeton University Press.

Hughes, A., & Hughes, A. (Directors). (2010). *Book of Eli* [Motion Picture].

Konstantopoulos, T. (2006). *Notes on Survival Models.* Edinburgh: Heriot - Watt University.

Krusell, P. (2014). *Real Macroeconomic Theory.*

Luckerson, V. (2014, December 2). *5 Very Smart People Who Think Artificial Intelligence Could Bring the Apocalypse.* Retrieved January 13, 2016, from Time Website: http://time.com/3614349/artificial-intelligence-singularity-stephen-hawking-elon-musk/

Maschler, M., Solan, E., & Zamir, S. (2013). *Game Theory.* New York: Cambridge University Press.

Shapley, L. (1953). Stochastic Games. *Mathematics: LS Shapley*, 1095 - 1100.

Stewart, W. (2009). *Probability, Markov Chains, Queues, and Simulation.* New Jersey: Princeton University Press.

UNHCR. (2015, December 29). *STORIES FROM SYRIAN REFUGEES: Discovering the human faces of a tragedy.* Retrieved January 13, 2016, from The UN Refugee Agency Website: http://data.unhcr.org/syrianrefugees/syria.php

United Nations. (2016). *Overview: United Nation*. Retrieved January 13, 2016, from United Nations Website: http://www.un.org/en/sections/about-un/overview/index.html

United Nations. (2016). *Overview: United Nations*. Retrieved January 13, 2016, from United Nations Website: http://www.un.org/en/sections/about-un/overview/index.html

Varian, H. (1992). *Microeconomic Analysis.* New York, NY.: Norton & Company, Inc.

von Aurer, L. (1998). *Dynamic Preferences, Choice Mechanics and Welfare.* Berlin: Springer-Verlag.

von Neumann, J., & Morgenstern. (1944). *Theory of Games and Economic Behavior.* New Jersey: Princeton University Press.