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ABSTRACT

Sharing economy firms, based on online platforms, have become strong competitors of traditional firms in many services sector, including the taxi industry. The aim of this article is to provide an economic framework for the analysis of this rivalry. Besides the literature on sharing economy, the characteristics of online platforms are summarised, which explain the quick expanse of successful sharing economy ventures. Based on the theoretical literature it is shown that for service providers, the choice between sharing economy platforms and traditional firms resembles the ”standard wars”, the competition between technological standards. A coordination game is presented to analyse the competition between taxi companies and Uber. The model not only reveals the different equilibria and the possible strategies of the players, but also shows the importance for adequate regulatory policy.

1. Introduction

Consumption habits and the provision of services have undergone significant changes in the recent years. The development of information and communication technology (ICT) enabled the emergence of new distribution channels based on the constant flow and exchange of data between users and information systems. Smartphones and other devices, with constant connection to the Internet, enable any individual to cooperate with others on a real-time basis. Such connectivity increased the potential of online platforms, which had already transformed such sectors as retail (Amazon), entertainment (Netflix, Spotify) or classified advertisements (Craigslist). Online platforms, by decreasing transaction costs, facilitate not only transactions between consumers and firms (business-to-consumer transactions), but also direct transactions between individuals (peer-to-peer). Examples for such peer-to-peer transactions include the rental of one's bedroom for tourists (Airbnb), ride-sharing (BlablaCar), or the commission of small tasks (TaskRabbit). The new business models based on platforms and peer-to-peer cooperation are usually labeled under the umbrella-term of the *sharing economy*.

Online platforms enabled the exchange of assets and provision of services to virtually anyone interested, which has a significant impact on numerous sectors, especially where entry costs had been previously high. Such sector is the heavily regulated taxi industry, with traditionally high restrictions for entry. Typically, an occupational license is required from taxi drivers, and their number is limited by medallions. Furthermore, it is also common practice to regulate taxi fares. In such an environment appeared Uber, a platform-based taxi company, rearranging the market and rendering the existing regulations obsolete. Uber's business is based on a mobile app, which directly connects drivers and customers looking for a ride. Therefore, Uber enables the provision of taxi services without complying to the regulations obligatory for the industry.

One of the most popular platforms is Uber, which operates in the taxi industry. The success of Uber may be found in different determinants. Firstly, Uber has brought innovative solutions and enhanced user experience, which is valued by its customers. The major feature of the Uber smartphone application is the booking of drivers and the tracking of their location. Additionally, Uber is using a dynamic pricing

algorithm to equilibrate supply and demand, which results in short waiting time. On the other hand, traditional taxi companies are under strict regulation, which may create an unfair advantage for Uber, which is not following many of these obligations. Typically, regulations for taxi services include a control of entry, licensing and performance requirements, financial responsibility standards and a price cap for journeys (Geradin, 2015). Meeting these requirements is costly, which is reflected by the usually higher prices of traditional taxi services (Silverstein, 2014). However, a service provided by licensed taxi companies may be valued by consumers for safety reasons.

Uber and similar platforms significantly eased these restrictions, as one can provide a taxi service without complying to the expensive regulations. This suggests these disruptive firms enjoy a cost advantage over traditional firms, as they successfully avoid costly regulation. Regulatory authorities all over the world are facing the challenge how to react to Uber and other sharing economy platforms. Proponents of restrictive regulation approach argue that Uber drivers benefit from unfair competitive advantage, which puts a huge pressure on traditional taxi drivers. However, proponents of liberal regulation (do nothing scenario) argue that platform services should be left unregulated as more innovative and cost efficient actions should not be penalized to secure traditional inefficient services. Regulatory dilemmas will certainly continue to appear in the future, given the disruptive nature of ICT progress. In the Communication entitled 'A European agenda for the collaborative economy' (2016), the European Commission provided a non-binding guidance on how existing EU law should be applied to sharing economy. According to the Commission, as long as the collaborative platform provide a service at a distance, by electronic means and at the request of the consumer, they provide an information society service, which should be exempt from prior authorisation or other additional regulation. However, this condition has to be examined on a case-by-case basis, following some criteria regarding the control of the platform over the provider.

In the case of consumers, switching costs are usually low, therefore they can easily use both traditional and collaborative services. In the supply side, however, service providers are effectively locked to the chosen business model. Service providers need to choose between traditional companies and platforms, while being subject to network externalities (incumbent users benefit from an increasing number of new users) and switching costs (adjustment to regulations, loss of online reputation etc.). Standard wars, describing the dilemma of consumers related to the choice between technological standards, e.g. between operational systems, are characterised by the same properties (Elsner et al., 2014). Therefore, the competition between traditional firms and platforms with network externalities and switching costs can be modeled using methods already applied for the analysis of standard wars.

The aim of this article is to provide a theoretical framework for the analysis on the competition between Uber drivers and licensed taxi drivers. The dynamics and market equilibria of such competition is presented, along with the role of regulations.

The structure of the paper is as follows: section 2. examines the functioning of Uber in Poland, and compares it to traditional taxi companies. Section 3.explains the success of collaborative services based on the economic literature on platforms. Section 4. introduces technological standards, while section 5. presents a coordination game for the analysis of competition in the taxi sector.

2. Uber vs Traditional Taxis in Poland

We begin the analysis with a brief summary on the activity of Uber in Poland. Uber entered the Polish market in 2014, operating firstly only in Warsaw, then expanding the network to Cracow, Tricity (Gdynia, Gdansk, Sopot) Poznan, Wroclaw and Lódz (UOKIK, 2016). The exact number of Uber drivers is unknown: according to the company, more than 40 000 drivers applied to become a partner (UOKIK, 2016). In comparison, the overall number of taxi licences was 61300 at the end of 2014, out of which

10500 were issued in Warsaw (UOKIK, 2016). The number of taxi licenses in Warsaw has been increasing since then, reaching more than 11000 at the end of 2015 (City of Warsaw, 2016). This shows that not only the overall number of drivers increased, but also of traditional licensed drivers.

In order to become a driver on the platform, Uber does not require a taxi license. Besides a standard verification (e.g. certificate of good conduct), Uber just requires a certificate of private hire, meaning that Uber drivers are not employed by Uber and need to cover their own social security. On the other hand, Uber drivers are not required to pay for more expensive insurance typical for taxi drivers, but can choose cheap, basic constructions. Drivers receive the payment from passengers through Uber, which deducts a share from every transaction, without a fixed monthly payment. When it comes to the vehicle, Uber requires cars that are no older than 15 years with minimum 4 doors.

Furthermore, to further decrease entry costs for drivers, Uber allows the activity of intermediaries, which advertise themselves on the official Uber website. Drivers can provide services via these intermediaries on Uber, without registering as an entrepreneur or owning a car. The intermediary company is arranging the bulk of the paperwork and provide the vehicle in return for a daily or weekly commission. There is a growing number of Uber services, varying in vehicle types and prices. In the case of Poland and Slovakia, there are two available Uber services: Uber POP and the more expensive Uber Select. In the Czech Republic there is also Uber Black, where professional drivers are offering rides. In London, Uber is also offering Uber XL (greater cars) Uber Access (for disabled customers) and the higher-end Uber Lux. Uber introduced also a car-sharing option called Uber Pool in selected cities (not available in V4). Uber Pool connects passengers traveling to the same direction, therefore enabling lower fares and better utilisation of the driver's vehicle.

What are the requirements to become a taxi driver in Warsaw? Firstly, the driver candidate must attend a taxi course and pass an exam. The price of such courses are varying, the average of three different schools (first offers found by Google) is 297 PLN (69 EUR). The price of the exam is 260 PLN, or approximately 60,5 EUR (City of Warsaw, 2016). The candidate also must pay a license fee of 320 PLN for 15 years (74 EUR). The driver also has to cover the cost for medical examinations. Furthermore, the driver's vehicle need to fulfill a number of additional requirements, including the possession of a taxi-meter and a taxi sign on the roof (Ministry of Economic Development, 2015). Once the driver is in the possession of the license and has equipped the vehicle, it has two main options: join a taxi company or a taxi platform (with or without an affiliation to a traditional taxi company). Traditional taxi companies provide the driver access to their clients, in return of a monthly provision fee. The fee usually contains a fixed membership fee, and also commission from every transaction. Usually, the driver is not employed by the taxi corporation, but works as registered entrepreneur with own firm (private hire). Therefore, drivers need to pay social security for themselves.

Platforms appeared on the market aggregating the offers of traditional firms, and introduced the innovative solutions of their peer-to-peer counterparts. An example is MyTaxi, an app-based platform for traditional taxis, which offers all major innovations of Uber: booking and tracking of drivers, cashless payment etc. According to the company's website (pl.mytaxi.com/index.html), currently 45000 licensed taxi drivers can be booked in a number of EU countries. These solutions are attractive, as they adopt the major innovations introduced by Uber: instead of a central office, direct connection between the driver and passenger, cashless payment though the app, tracking of the driver etc. Therefore, such platforms are targeting consumers valuing the innovations of Uber, but also expecting a higher quality service that licensed drivers can provide. It is possible for drivers affiliated with traditional taxi companies to join such platforms, however, some of the corporations do not allow affiliated drivers to work additionally. The platforms are charging commission from every transaction- in the case of myTaxi it is 3 PLN.

To sum up, there is a number of significant differences between taxi and Uber drivers. Firstly, the

entry costs to become a taxi driver are higher, stemming from the necessity to acquire a license, taxi-meter and pass additional tests. Secondly, Uber drivers may benefit from additional cost-advantage, as they are not required to cover for taxi-standard insurance. Finally, Uber do not request a fixed monthly-fee, which enables Uber drivers to operate with lower fixed costs. On the other hand, Uber drivers, like the majority of taxi drivers, are registered entrepreneurs, paying income tax and social security (although there are different loopholes to avoid taxes in the case of both groups).

3. Uber: Platform Economy or Sharing Economy?

Let us now briefly analyse the business model of Uber. Uber is enabling peer-to-peer transactions by connecting two-sides of the market: drivers and passengers. The two sides are interacting via the Uber app, which is the channel for all transactions. The price is set by the Uber algorythm, which contains a base fee and rates dependent on the length and distance of the journey (Uber, 2017). Furthermore, the final price is dynamically changing: if demand is high, the base price is multiplied based on the number of available drivers and waiting costumers. The passenger is paying for the service directly to Uber, which is forwarding the fee to the driver, keeping a certain % of the service fee as commission. In short, Uber is serving with the necessary IT infrastructure for the transactions, while the taxi services are provided by the drivers. Therefore, Uber is essentially a platform for taxi services.

By the definition of the European Commission (2015), platform operating on two or multi-sided markets, facilitate interactions between two or more distinct, but interdependent groups of users, generating value for at least one of the groups. The different sides need the platform to capture the economic value from their interdependence (Evans and Schmalensee, 2007). In the case of two-sided markets, platforms ”get them on board” by appropriately charging them (Rochet and Tirole, 2003). Platforms are subject to network externalities, meaning that the more elements enter the network, the higher the value of the network to the individual user will be. Network effects distinguish platforms from other markets, where buyers and sellers realise gains from trade (Rochet and Tirole, 2003). While the rising number of users have a positive external effect on the incumbent users, it has a negative external effect on the users of the competing network (Elsner et al., 2014). This leads to direct mutual interdependence on the decisions of agents. Network effects help explain the boom of sharing economy and the success of certain firms, especially that of Uber and Airbnb. Taxi seekers and tourists would choose a platform with a high number of drivers and hosts in order to raise the probability of finding high quality service. In turn, drivers and hosts would also choose a platform with a high number of registered users, therefore this is a reinforcing process. After reaching a tipping point, online platforms can easily reach a dominant or even monopoly position on the market. Additionally, platforms can easily scale their activity, as they provide only the IT infrastructure, but do not need to invest in the physical assets necessary for the provision of the service or hire a large number of employees. The vast majority of costs rest on the service providers, while the platform itself is able to operate at close to zero marginal costs (Rifkin, 2014). In fact, many collaborative platforms claim that they only provide information society service.

Another mechanism of platforms is the reduction of transaction costs. Platforms offer a superior intermediation service by aggregating and processing previously impossible scope of information, reducing search cost and offering better match for the searching agents (Caillaud and Jullien, 2003). Besides search costs, platforms also reduce uncertainty and economic risk related to transactions. Firstly, platforms ensure transactions through serving the payment procedure: the seller receives the payment only once the buyer received the good or service. Secondly, platforms implement reputation systems, similar to online auction websites. Such reputation systems allow agents to distinguish between trustworthy and non-trustworthy counterparts, encourage to be trustworthy and discourage from dishonest actions (Resnick and Zeckhauser,

2002). These practices have been implemented by sharing economy firms. As Uber cannot verify the skills of the driver, it uses the rating system to control for the quality of the provided service. In case of poor ratings (below 4.6), Uber sends the driver warnings and may ban from certain Uber services (the more expensive Uber Select). Furthermore, if the driver scores less than 4.3 after the first 25 trips is banned from the service (Uber, 2017).

Whether Uber is part of the sharing economy is debated in the literature. While Botmsan and Rogers (2010) include the sharing, bartering, lending, renting, gifting, and swapping of assets in the definition of 'collaborative consumption', other authors proposed more restrictive approaches. Bardhi and Eckhardt (2012) argue that "sharing" is not an appropriate term to describe the activity of car-sharing (consumers gaining access to cars for short term periods) and introduced the term "access-based consumption", focusing on the difference between sharing and granting access to ownership. This definition was challenged by Belk (2014), on the other hand, who argued that "access-based consumption' is only a subset of collaborative consumption, which is "people coordinating the acquisition and distribution of a resource for a fee or other compensation" (Belk, 2014, p. 1597). Finally, numerous scholars emphasise that sharing economy platforms utilise underused assets or idle capacity, therefore a full-time service provision should be excluded from the landscape. Böcker and Meelen (2017) make such a distinction, defining sharing economy as "consumers granting each other temporary access to their under-utilized physical assets ("idle capacity"), possibly for money" (Böcker and Meelen, 2017). As Meelen argue in an opinion piece (Frenken and Meelen, 2015), Uber should not be considered part of the sharing economy, because the transactions are not induced by idle capacity. From the consumer point of view, Uber is not much different from a traditional taxi service: the driver takes the costumer from one place to another, at the time the costumer requests it. The only situation in which idle capacity is involved when the driver would travel without the passenger from point A to B anyway. The authors argue that there are also significant differences between the Uber services, such as Uber X and Uber Pool. While Uber Black or Uber X are clearly outside such definition of sharing economy, Uber Pool fulfills the criterium of putting idle assets to work.

To conclude, while Uber is a peer-to-peer service, the vast majority of transactions do not fulfill the criteria of the sharing economy. Firstly, following the widest definitions of the sharing economy (e.g. Belk, 2014), sharing economy companies connect owners of assets with those searching for the asset, such as cars. However, the presence of intermediaries suggest that a significant share of Uber drivers rent their cars in order to provide the service via the platform. Secondly, another argument is that 'sharing economy' companies generate value from underused assets, which are idle most of the time. Even if such argument would be valid for Uber, it could be also applied to traditional taxi companies as well.

4. Standard Wars

The main players on the taxi services market are Uber, taxi corporations and platforms for licensed drivers, such as MyTaxi. Consumers can relatively easily switch between the different platforms and companies, as they only bear the learning costs associated with using a new service. However, there is asymmetrical engagement between service providers and consumers. In the case of service providers, a change between different platforms can be costly, similarly to a change of employer: drivers have to fill in registration forms, validate identity and in the case of licensed drivers also pass exams. Furthermore, drivers switching platforms loose the previously built reputation. Most platforms award drivers with high ratings e.g. the myTaxi app gives priority to high-ranked drivers during the matching process. To sum up, drivers have to choose between the service providers, being subject to network effects and switching costs.

This problem resembles the competition between technological standards. "Standard wars" refer to

the competition between technologies with network externalities: operating systems (PC, Mac, Linux), microprocessor architectures (Intel, AMD, IBM) or data storage systems (VHS vs Betamax, Bluray vs HD DVD) etc. (Elsner et al., 2014). These standards are characterised by reduced or no compatibility, e.g. many programs are only available for the Windows or Mac OS platforms. Switching from one platform to another is costly: the customer has to purchase new equipment, learn its usage, and also count with the loss of investments into the previous standard. When switching costs are substantial (learning costs, new equipment etc), consumers are locked-in to the chosen standard, meaning that their equilibrium decision yields lower social welfare than an alternative. In the case of markets with network-effects, multiple equilibria are possible, e.g. full, partial or no adoption of a certain standard (Stango, 2004). Consumers benefit from using a standard with a large costumer base, as they have a higher probability to find another person with compatible technology and enjoy a wide variety of services, e.g softwares. This creates an incentive to capture a large customer base and become dominant in the market. This usually leads to a ”winner-take-all” outcome, as in the case of VHS vs Betamax (Stango, 2004).

In our example, drivers entering the market need to make the choice between Uber (no taxi license) or one of the taxi companies. In the case of a constrained number of drivers, drivers benefit from other drivers joining their platform, e.g. Uber drivers gain if other drivers also choose Uber, as passengers would prefer the company with more available drivers and lower waiting times. Following their choice, drivers can serve only one group of customers: e.g. regular taxi drivers cannot use the Uber app. Furthermore, high switching costs lead to a lock-in situation.

5. A Coordination Game Explaining the Competition between Sharing Economy Platforms and Traditional Firms

In order to analyse the competition between Uber and licensed taxi drivers, a coordination game used to model the ”standard wars” will be used. Let us make the assumption that the quality of the service do not differ between traditional and collaborative services, and users choose between platforms based on the number of service providers. Providers are subject to network effects: the more of them choose a certain platform, the higher the potential benefits, as consumers would follow them. Prospective drivers face the dilemma whether to join Uber or get a license and join a regular taxi company. Peer-to-peer platforms are characterised by low entry costs: the candidate must fulfill certain criteria, however, the procedure is easier and less expensive, than the entry into the traditional sector. For the sake of simplicity, drivers are divided only into two segments (Uber drivers and licensed drivers), without additionally differentiating between traditional taxi companies and platforms for taxi drivers.

The dynamics and outcome of such competition can be explained based on a simple coordination game, presented by Elsner et al. (2014, pp. 458-460) to explain the price war between competing technological standards. Our model translates the problem of drivers into a two-player coordination game: Player 1 (Driver 1) and Player 2 (Driver 2) have to choose between taxi companies (T) and Uber (U). Therefore, drivers choose between strategy S_t (Taxi company) or strategy S_u (Uber). The market share of the two platforms are noted as P_t (Taxi company) and P_u (Uber). In this simple game the market share of the two platforms is given by the share of drivers, as consumer demand is only dependent from the availability of drivers. This two-player coordination game can be depicted as following:

Drivers gaining a taxi license face an entry cost above the costs of joining Uber at the value of c.c comprises all costs above the cost of joining Uber: the cost of acquiring a license for the provision of taxi services, and the necessary equipment for the vehicle. c is mainly determined by the regulatory authorities, therefore it is exogenous for taxi companies. The two payoffs are also differentiated by parameters α and

Table 1. Price war coordination game

		Player 1	
		T	U
Player 2	T	$(1-c+\alpha, 1-c+\alpha)$	$(1-c, 1)$
	U	$(1, 1-c)$	$(1+\beta, 1+\beta)$

Source: Own elaboration

β. Parameter α is controlled by taxi companies, while parameter β by Uber. The competing sides can use these parameters to attract drivers and gain larger market shares. The parameters in both cases mean factors like the share of turnover remaining for the driver, flexibility of working hours, social security and other benefits. As seen in Section 2., taxi and Uber drivers are often self-employed, working in a similar business model, with the main difference in the share of commission, the car leasing possibilities and overall work culture. The expected payoffs are the following (with α, β, $c \geq 0$ and $\alpha \geq$ c):

$$\pi_T(t) = 1 + (\alpha)p_T(t) - c \tag{1}$$

$$\pi_U(t) = 1 + \beta(1 - p_T(t)) \tag{2}$$

The model allows drivers to reconsider their choice from time to time, which leads to a dynamic process, described by the following replicator equation (explained in the Appendix):

$$\frac{dp_i(t)}{dt} = p_i(t)\Big(\pi_i(t) - \sum_{j\in=T,U} p_j(t)(\pi_j(t)\Big) \qquad i = T, U \tag{3}$$

Substituting the payoffs into the replicator equation results in the following:

$$\frac{dp_T(t)}{dt} = p_T(t)\Big(1 - p_T(t)\Big)\Big((\alpha+\beta)\Big)p_T(t) - \beta - c\Big) \tag{4}$$

There are three equlibria for such system:

- $P*_{T,1}$=0
- $P*_{T,2}$=1
- $P*_{T,3}$=$\frac{\beta+c}{\alpha+\beta}$

The stability determining eigenvalue is given by:

$$\lambda(P_T) = \frac{\partial dp_T(t)/dt}{\partial p_T(t)} = -3(\alpha+\beta)p_T^2 + 2(\alpha+2\beta+c)p_T - \beta - c) \tag{5}$$

Therefore, $P^*_{T,1}$ and $P^*_{T,2}$ are always stable equilibria (λ <0), while $P^*_{T,3}$ is always unstable (λ >0). How can this result be interpreted? The stable outcomes mean a complete monopolization of Uber ($P^*_{T,1}$=0 $\rightarrow$ $P^*_{U,1}$=1) or taxi companies ($P^*_{U,1}$=0 $\rightarrow$ $P^*_{T,1}$=1). The more interesting case is represented by $P^*_{T,3}$, as this is an unstable market sharing equilibrium, which separates the basins of attraction between the two stable equlibria. For P_T <$P^*_{T,3}$, the dynamic goes towards $P^*_{T,1}$, while in the case of P_T >$P^*_{T,3}$ towards $P^*_{T,2}$ (Elsner et al., 2014). The two competing firms can influence $P^*_{T,3}$ through α and β: the taxi company's aim is to decrease $P^*_{T,3}$, while Uber's goal is the opposite, therefore taxi companies will try to increase α, and Uber will boost β.

This means a trade-off for greater market share. The competing firms will try to attract drivers, often sacrificing profit. Both Uber and traditional taxi corporations may either increase the earnings of drivers or improve their working standards. As an example, Uber could decrease the commission charged from drivers, while taxi corporations could resign from the monthly fixed fee, introducing a similar system to Uber, where the driver only pays after the actual transactions. The competing players can also reimburse the costs of drivers (fuel, services etc). A further important issue is the question of employment: the living standards of drivers could be increased by employing them, instead of the present "partner" system. This question is going to remain in the centre of the debate: a UK employment court ruled in October 2016 that Uber must pay national living wage and cover holiday pay to the drivers (Osborne, 2016).

Finally, authorities may influence the competition through c. This is indeed in the centre of the heated debate regarding policy-making, described in section 4. If firms like Uber are benefiting from unfair competitive advantage, authorities may use c to create a level playing field. The requirement from Uber to satisfy the same regulations as taxi drivers (license, taxi-meter etc) would completely eliminate c (as it stands for the difference in entry costs between platforms). Authorities could also choose the other way of decreasing c by modifying existing taxi regulations and easing the entry costs of the sector. A more probable solution would not eliminate the necessity of the license, but a taxi-meter would not be required any more, as it is not necessary in the smartphone-era. Either way, a decrease in c would contribute to an increase the market share of regular taxis.

To sum up, a novel model has been presented for the analysis of the competition between traditional firms and sharing economy platforms. On the example of Uber and the taxi industry, the possible market share equilibria have been presented. Furthermore, the possible strategies of Uber and taxi companies have been analysed, including the role of policy.

6. Conclusions

The analysis of successful sharing economy ventures suggest a triumph of online platforms, instead of a shift towards collaborative consumption (e.g. joint ownership of assets). The characteristics of online platforms, like network effects, nearly zero marginal costs and reduction of transaction costs enabled the rapid growth and spread of sharing economy services. Sharing economy platforms became strong rivals of traditional firms in many services sectors, which created a yet unsolved regulatory challenge.

The major contribution of this analysis is the presentation of the competition between sharing economy and traditional firms as a war between technological standards. From the perspective of a full-time service provider, the choice between a platform and a traditional firm is similar to the dilemma of choosing a standard. Platforms, just like standards, are subject to network externalities and lead to the lock-in of users. A novel framework was presented to analyse the rivalry between platforms and traditional firms on the example of Uber and the taxi industry. The coordination game revealed the different market share equilibria and the possible strategies of platforms and traditional firms to win the war. Furthermore, the analysis showed the crucial role of adequate policy to create a level playing field in the taxi services sector.

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Appendix

This section briefly presents the replicator equation that is presented in section 5, based on Elsner et al., 2014. The following differential equation describe the change of state variables in time:

$$\frac{d\theta(t)}{dt} = F_d(\theta(t))$$

The state variables are the spheres of specific types of agents i in the population:

$$\sum_i \theta_{i,t} = 1$$

The agent types evolutionary potential is given by the evolutionary fitness $f_{i,t}$. We also define the average fitness of the population:

$$\Phi_t = \sum_i \theta_{i,t} f_{i,t}$$

The evolutionary performance of the agent types is determined by the relation of their individual fitness and the average fitness of the population, hence:

$$\frac{d\theta(t)}{dt} = F_d(\theta_i(t), f_i(t), \Phi_t))$$

In section 5, the state variables are $p_i(t)$ for i=T,U, while the fitness values are given by the expected profit.

The value of the stability determining eigenvalue for the different equlibria:

- $P*_{T,1}$=0
  $\lambda(P_T)$= -β-c <0
- $P*_{T,2}$=1
  $\lambda(P_T)$=-α-4β+c <0
- $P*_{T,3}$=$\frac{\beta+c}{\alpha+\beta}$:
  $\lambda(P_T)$=-3(α+β)$\left(\frac{\beta+c}{\alpha+\beta}\right)^2$ + $2(\alpha+2\beta+c)\left(\frac{\beta+c}{\alpha+\beta}\right)$-$\beta$-c=$\frac{-3(\beta+c)^2+2(\alpha+2\beta+c)(\beta+c)-(\beta+c)(\alpha+\beta)}{\alpha+\beta} \rightarrow$
  -$3(\beta+c)^2+2(\alpha+2\beta+c)(\beta+c)-(\beta+c)(\alpha+\beta)$=$\Big(\beta+c\Big)\Big($-3($\beta+c$)+($\alpha+3\beta+2c$)$\Big) \rightarrow -3\beta-3c+\alpha+3\beta+2c = \alpha-c$>0 (as α >c)