SYSTEM DYNAMICS MODELLING OF PUBLIC ICT PLATFORMS[1]

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Abstract
The objective of this paper is to show how system dynamics modelling can be applied to simulate the behavior of information communication technology based platforms to formulate and validate strategies or development policies of these platforms in the public sector. Typical platforms in the domain of public sector for instance are mobile apps connecting the sides of users and developers, or horizontal or vertical government portals connecting different authorities on one side and users or corporations on the other side. We show in our contribution how system dynamics provides new insights for modelling two-sided markets in general and public ICT platforms in particular. Conclusions and results of our work are mainly theoretical: as an initial step we extended the classic microeconomic equilibrium models mainly concerned with how to determine pricing of the opposing sides into more general parameters of platform quality, externalities and causality analysis of different variables. Based on these theoretical models we suggest simple inference to policy making and some pragmatic decisions in connections with public ICT platforms.

Keywords: *public platforms, two-sided markets, system dynamics*

1. Introduction

Platforms, or, two-sided markets as they call them in microeconomics, have become essential business models in digital transformation. We argue, that this is a surprisingly neglected logic in the case of public administration platforms, or portals where governments want to achieve a critical mass of citizen and business participants on one side, and a wide variety of administrative services on the other side. By applying the microeconomic theory of two-sided markets and then modeling the dynamics of same-side and cross-side network effects we show how effective government portal strategies can be created. We base our arguments on conceptually using the experience from the business sector where exploiting the capabilities of information communication technologies (ICT) by generating an ecosystem which enables to connect different economic actors and generates network effects and externalities results in staggering economic performance. Amongst the top 100 corporations in the world 60 generate most of their revenues from the operation of platform networks, and the market capital of platforms in recent years has been estimated around 4000 Billion USD globally [1].

Firstly, we introduce summarize the concept of the classic monopoly two-sided market model using microeconomic theory and explain how it is interpreted to public platforms. Secondly, we extend the model to a dynamic space, and show how the behavior of participants can be modeled using system

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dynamic simulation, and illustrate typical patterns of platform dynamics. Finally, we present some suggestion how the dynamic platform models may enhance platform strategies in general and specifically in the public sector.

2. A microeconomic model of monopoly platforms based on Armstrong [2]

Following the seminal contributions of Caillaud and Jullien [3], Rochet and Tirole [4], [5], and Armstrong [2], such models have become widely used as building blocks in the microeconomic theory literature. Note that this literature uses the terms two-sided market/ two-sided platform/ multi-sided market and multi-sided platform interchangeably to describe the same type of markets. Various extensions of these models are used to investigate intermediary platforms that connect two distinct sets of agents where the number of agents on the one side affects the utility of agents on the other side (for the most recent survey, see [6]). As explained above, in this paper, we propose a novel use of such models; therefore it is worth describing a simple model of two-sided platforms in detail.

The most tractable model of a monopolistic two-sided platform that still captures the essential trade-offs is arguably a simplified version of [2]. Thus we proceed by further simplifying the model in [7, p. 630], which itself builds on the former, very general model.

There are three types of agents in the two-sided market we model: an intermediary platform, buyers and sellers. In this example the platform is a price-comparison website like Amazon, Google Flights, booking.com, Airbnb, etc. Similarly, in the public settings these could be the horizontal portals collecting services such as ordering documents, reporting tax, applying for passports and personal IDs, or organizing public procurement. Importantly, we only refer to the two groups as buyers and sellers for expositional purposes, the model is general enough to encompass situations when the two groups are e.g. smartphone users and app developers (the market for operating systems); heterosexual men and women (the market for dating websites or nightclubs); drivers and passengers (the market for ride-hailing services); or in our public domain citizens and government agencies.

The key assumption which defines a two-sided market is that the utility a buyer derives from joining the platform depends on the number of sellers on the other side of the market, and vice versa, the profit of a seller depends on the number of buyers connected to the platform. Indeed, in the price-comparison website example (and all the other examples above) it is natural to think that the more sellers there are, the more choices a buyer has and in addition competition is fiercer, thus buyers' utility in increasing in the number of sellers on the platform. Similarly, everything else equal, the more buyers there are on the platform, the higher sellers' expected sales are, thus the higher their profit. Following a large part of the economics literature, we call this effect a *cross-group externality*. Note that it is common to refer to it as an *indirect externality*.

In all of the motivating examples above, the cross-group externalities are positive on both sides: the more agents are connected to the platform on the one side, the higher the utility of the agents on the other side. In the rest of this paper, we will focus on this case as we believe this is the relevant assumption for public platforms. However, it is worth noting that in some important two-sided markets one group exerts a negative cross-group externality on the other. The most prominent of such markets are advertising: for both traditional newspapers and websites, more advertisement tends to alienate readers, whereas the advertisers clearly benefit from a high number of readers. Therefore, one of the cross-group externalities are negative, and the other one is positive. Clearly, a market where both sides dislike the presence of the others (i.e. both cross-group externalities are negative) is unlikely to arise.

Having defined the three groups of agents in the model, we can now turn our attention to the pricing structure. Intermediary platforms typically have the opportunity to charge two types of prices to both buyers and sellers connecting to them: (i) usage fees that buyers and/or sellers have to pay for each transaction, or (ii) membership fees that buyers and/or sellers have to pay only once to connect to the platform and is independent on the number of transactions they make afterwards. In reality, many platforms charge a combination of the two, see e.g. the fee structure of Amazon Marketplace or eBay for sellers. Importantly, [2] demonstrated that in the case of monopolistic platforms, which is the focus of this study since public portals are either in this status or intend to achieve this, the two pricing structures lead to the same market outcomes and welfare results. Therefore, in the following we will assume that the platform only charges membership fees, which is arguably the simpler case to analyze. Therefore, we assume that the monopoly platform has two tools to maximize its profits: it charges membership fees M_B and M_S for buyers and sellers, respectively. The main question is how the platform determines these membership fees optimally, and what are the managerial implications and welfare effects of such strategies.

For simplicity, assume that on the platform each buyer has a unit demand for each seller's product and sellers are willing to transact with each buyer. Moreover, let the terms of these transactions be independent of membership fees (e.g. because membership fees are already sunk costs at the time of transactions). Then each seller will derive the same profit π per transaction and each buyer will derive the same utility u per transaction. Therefore, the total surplus of a seller joining the platform can be written as

$$v_S = n_B \pi - M_S + k \ldots (1)$$

where n_B denotes the number of buyers and k their so called stand-alone benefits, i.e. their utility when there are no agents on the other side of the platform. For example, even if there are no sellers of a product, buyers can benefit from the product description or previous ratings on price-comparison websites. Similarly, in public platforms news, or general information is valuable to both sides. Indeed, given our assumptions, the sellers derive profit π exactly $n_B$times, and has to pay M_S to the platform plus they get their stand-alone benefits. Similarly, the total surplus of a buyer joining the platform can be written as

$$v_B = n_S u - M_B + k \ldots (2)$$

where n_S denotes the number of sellers on the platform and k is again their called stand-alone benefit. Clearly, the total surpluses are increasing in u and π which capture the cross-group externalities in this model. As they are both assumed to be positive, each side benefits from an increased presence of agents on the other side. We make the technical assumption $u + \pi < 2$ which we will motivate after solving for the demands on the platform.

To determine how many buyers and sellers join the platform for a given pair of membership fees, one has to define their outside option (i.e. their utility when not joining the platform). Let these outside options be uniformly distributed on $[0, o]$, where o denotes the total mess of buyers and sellers, respectively. Then the equilibrium number of buyers and sellers on the platform will be simply given by the functions $v_S = n_S$ and $v_B = n_B$. Replacing these values to the equations above and solving the resulting system of equations leads to demands

$$n_S(M_S, M_B) = \frac{k(1+\pi) - M_S - \pi M_B}{2 - \pi - u} \ldots (3)$$

and

$$n_B(M_S, M_B) = \frac{k(1+u)-M_B-uM_S}{2-\pi-u} \dots (4)$$

One of the key features of these demands is that buyers' demand decreases in M_B, but also in the price of sellers M_S. This reflects the cross-group externality of sellers on buyers. In particular, a larger M_S reduces the number of sellers, which makes the platform less attractive for buyers as well. To see this, if buyers do not benefit from the presence of sellers (i.e. if $u = 0$), buyers' demand is independent of M_S.

Notice that without assumption $u + \pi < 2$, the optimal demands show that infinitely high membership fees would be optimal: as the denominator is negative, decreasing the numerator by higher membership fees would increase demand and therefore the total profit. This is clearly unrealistic, which is why the entire economics literature on two-sided markets makes this assumption.

Now we can write the maximization problem of the monopoly platform as follows:

$$\max_{M_S, M_B} n_S(M_S, M_B)(M_S - C) + n_B(M_S, M_B)(M_B - C) \dots (5)$$

where C is the marginal cost for the platform of serving an extra buyer or seller (we assume $C < k$ to avoid the trivial case of an empty platform). Replacing the demand functions derived above into the profit function, deriving it according to $M_S$and M_B and solving the system of first order conditions gives us the optimal membership fees as a function of the parameters of the model. It is straightforward to see that the profit function is concave quadratic in the membership fees so the first order conditions indeed define a maximum. We have

$$M_S^* = \frac{k(1-u)+C(1-\pi)}{2-\pi-u} \dots (6)$$

and

$$M_B^* = \frac{C(1-u)+k(1-\pi)}{2-\pi-u} \dots (7)$$

A first key result is that the side that exerts a larger cross-group effect on the other side will be subsidised in optimum, i.e. that side will have a lower membership fee. Indeed, consider the case when buyers exert a larger cross-group external effect on sellers than vica versa, i.e. $u > \pi$. This directly leads to the optimal membership fees $M_B^* < M_S^*$. We often observe such discounts in real-word two-sided markets, for example many nightclubs offer reduces or even free entry to women, buyers can typically use price-comparison websites for free, etc.

Regarding public portals, this demonstrates clearly why the citizen side should be subsidized in order to achieve optimum profit – or public benefit in this setting. This recognition is even more important and pragmatic, if we also interpret price in this case as the transaction cost for citizens using the platform. The easier to access and use, the lower this price is.

Another key observation is that the platform benefits from creating a "virtuous cycle" of more sellers attracting more buyers, more buyers attracting more sellers, and so on. The platform can then partially extract the increased utility of buyers and sellers in the form of increased membership fees. This result hinges having positive cross-group externalities on both sides, as one can see from the optimal profit value:

$$\pi^* = \frac{(k-C)^2}{2-u-\pi} \dots (8)$$

In other words, the profit of the platform is increasing in both externalities because the happier sellers are to have buyers, the easier to attract them, and the larger transaction fees the platform can charge to them. As a result, the monopoly's profit will increase.

As the above results demonstrate, one way of creating such a virtuous cycle is subsidizing one side of the market. In the past decade, this lesson has become widespread in business circles as well. Indeed, there is anecdotal evidence that when creating a startup, many companies start by asking themselves which side of the market to subsidize, not whether they should subsidize one at all[3]. In the case of public platforms the chicken-egg problem is usually cracked by starting to build up supply on the seller side (government services) and subsidies the buyer side (citizens and corporations).

3. Some dynamic models of monopoly platforms

The model based on [2] described in Section 2 is a static model, by assumption all interactions take place simultaneously. As usual in the industrial organization literature, the model assumes perfectly rational agents on both sides of the platform, who form correct believes about the action of others. Based on these beliefs they maximize their utility simultaneously which leads to the Nash equilibrium of the game as described above.

In reality, the dynamics of acquiring new customers can be crucial for a platform. Although it is present in the above model in a simplified way through beliefs, it can certainly be fruitful to open the black box of platform dynamics and investigate more directly its effect on customers and platform profit. In this Section, we describe two models that attempt this; [8, 9].

The main contribution of [9], which is essential in the case of public platforms, is documenting that the customer base can be viewed as a critical factor in the case of two-sided markets. More precisely, the article argues that the size of the two markets a platform connects (e.g. the number of citizens and government services) constitutes resource heterogeneity. Resource heterogeneity, in turn, acts as an isolating mechanism for platforms. Identifying isolating mechanisms is key in the resource-based view of competitive advantage [10] and the literature had not discovered the installed customer base on the two sided as an isolating mechanism before. Therefore, the main goal in [9] is to build a model that demonstrates that the size of its customer base can lead to lasting competitive advantage for a firm.

In more technical terms, the article argues that it is thanks to the presence of positive cross-group externalities that the platform can turn their customer bases into critical resources which then brings about sustainable competitive advantage. They focus on monopoly platforms and competition with two-sided single-homing, i.e. a situation in which agents on both sides join exactly one of the two competing platforms. As argued above, the monopoly platform is more relevant in the public platform context, so in what follows we describe their dynamic monopoly model.

To demonstrate the main point, we put a simplified version of the standard monopoly platform model (as described in Section 2.) in a dynamic context. This allows then to study the growth of a monopoly platform in a stylized way. For tractability, we sacrifice one of the key elements of the static models, namely, prices are no longer endogenously determined, instead, prices are given, which is very

[3] https://www.applicoinc.com/blog/7-strategies-solving-chicken-egg-problem-startup/

plausible in public platforms. With these simplifications, the main question can be focused to the evolution of the sizes of the two customer bases on the two sides of the market.

3.1. Basic setting

Using the above notation, let n_B denote the number of buyers and n_S the number of sellers on the platform. As in [2], this model also makes the simplifying assumption that all agents interact with all agents on the other side of the platform, thus the number of transactions are also given by, n_B and n_S.

Slightly more general than the model in the previous section, [9] allows for two types of fees that the platform can charge: in addition to membership fees M_S and M_B, they also allow for per-transaction fees r_S and r_B for sellers and buyers, respectively. However, they normalize the stand-alone benefit to zero, i.e. $k = 0$.

Now one can write the net benefit of sellers and buyers, NB_S and NB_B, respectively, as follows:

$$NB_S = (\pi - r_S)n_B - M_S \dots (9)$$

and

$$NB_B = (u - r_B)n_S - M_B \dots (10)$$

Clearly, these net benefits are increasing in u and π which capture the cross-group externalities in this model, as before. Moreover, it makes sense to assume $u > r_B$ and $\pi > r_S$ otherwise no transaction would take place in this market. This is assumption is not easy to maintain in a public platform, where buyers often experience high transactions costs (ie. difficulties to use the portals) compared to the value of services they receive, often resulting in abandoning government e-services for other e.g. off-line options.

3.2. Growth dynamics

Next, the main contribution of this [9] assumes an explicit dynamic process for the platform to acquire new customers or to lose existing ones. The model assumes that each participant is the same from the platform's point of view, therefore on the micro level the order of joining the platform is random. However, importantly, the authors assume that on the macro level the net benefits drive the diffusion process. In other words, they formalize the intuitive idea that the higher the net benefit of a buyer is in a given period, the more buyers will join the platform. The same assumption is made for sellers. This is a typical approach in the system dynamics literature applied to two-sided platforms.

Formally, the authors assume that on each side of the market, the rate of adaption of the platform is proportional to the net benefit the platform provides. As a direct consequence, the two-dimensional dynamic system describing this market writes as

$$\dot{n}_B(t) = \alpha[(u - r_B)n_S(t) - M_B] \dots (11)$$

and

$$\dot{n}_S(t) = \beta[(\pi - r_S)n_B(t) - M_S] \dots (12)$$

where

t denotes time, $n_B(t)$ denotes the number of buyers and $n_S(t)$ the number of sellers at time t. Moreover, $\dot{n_B}(t)$ and $\dot{n_S}(t)$ denote the rate change (increase or decrease) in buyers and sellers at time t, respectively. The parameters α and β denote the speed of diffusion and they are assumed to be strictly positive.

Notice that according to the above formulation, if the net benefit for a group is positive then there are more agents of this group joining the platform. Conversely, when the net benefit is negative, customers are quitting the platform.

3.3. The unique equilibrium and its interpretation

The main mathematical result of [9] is the identification of the unique equilibrium of this dynamic system. It is a saddle point described by

$$\overline{n_B} = M_B/(u - r_B) \ldots (13)$$

and

$$\overline{n_S} = M_S/(\pi - r_S) \ldots (14)$$

This means that the system can have three different types of long-term behaviour depending on the initial number of agents connected to it. First, if the initial demand is below the saddle path then the platform dies out, i.e. loses all buyers and sellers. Second, if the system starts above the saddle path then it will grow towards infinity. Third, if the system starts on the saddle path then it will converge to the equilibrium point $(\overline{n_B, n_S})$.

Based on the authors of [9] we can give the following interpretation. It is the membership that makes potential participants into platform customers, therefore it is the membership that converts external factors into critical resources of the firm. Sun and Tse in [8] and [9] explained their results rooted in the resource based view of the firm. We recommend the use of these terminologies and theoretical foundations to explore the dynamics of public platform behaviour and examine how sustainable growth or equilibrium can be established. For this we show in the next section how system dynamics can be applied.

4. System Dynamics

System Dynamics (SD) is a method for studying, designing, and managing complex feedback systems by modelling their macroscopic structure through causal loop diagrams and simulating their behaviour through stock-flow models in a top-down manner [11]. SD models are deterministic continuous compartment models, working with differential equations. The great strength of the SD methodology is its high abstraction, educational clarity, and computational robustness [12].

In Figure 1. we depicted a causal loop illustration of a general platform model using system dynamics [13]. We can identify reinforcing causal loops (R1, R2, R3) which generate growth of the variables such as revenues, number of users and providers or development efforts; and we can also spot balancing loops (B1) referring to [9] where variables change in opposite directions – the growth of end users for instance reduces the competitive effort, which directs the platform towards equilibrium.

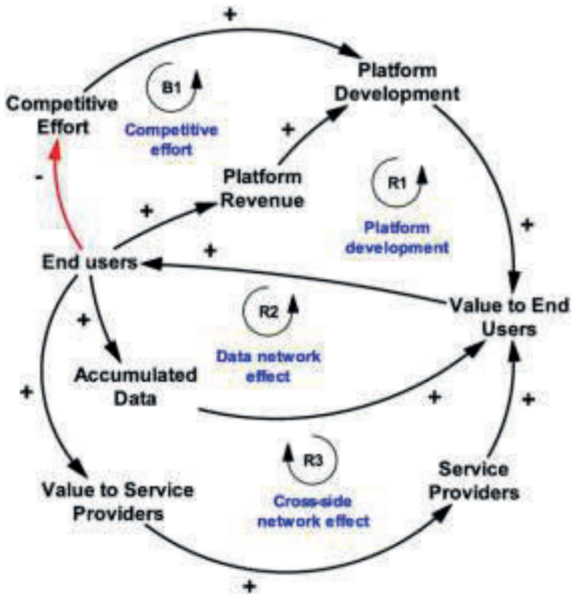

Figure 1: Causal Diagram of Platform Development by Ruutu, Casey and Kotovirta [13]

Another system dynamics model is shown in Figure 2. taken from [14] using stock and flow technique [12].

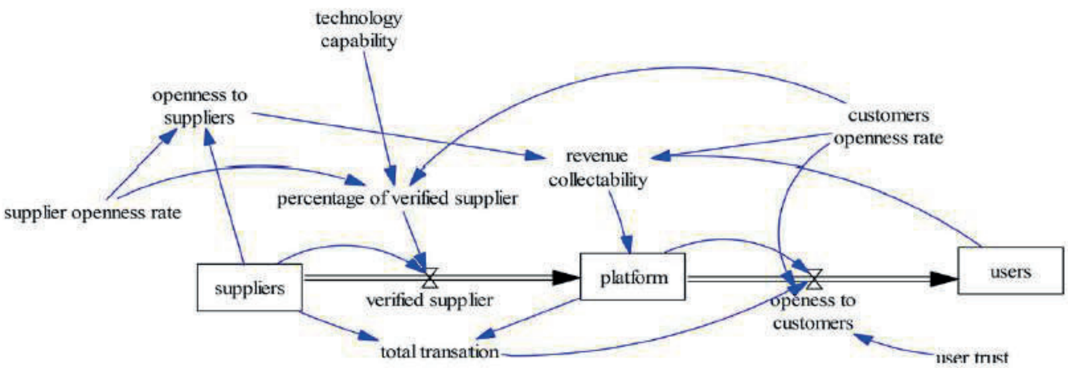

Figure 2: Stock and Flow Diagram of a general platform by Yun, Won, Park, Yang, and Zhao [14]

In Figure 2. we are able to study the three key stock (or state) variables – number of suppliers, the platform value, and the number of users. Their values increase directly by the flow (or derivative) variables – in this case these are the openness and the number of "verified" suppliers together with other modifiers such as technology capabilities or users´ trust.

Stock and flow models serve the visual representation of the differential equations such as we have seen in Section 3. describing the rate of change in our dynamic systems. Figure 3. shows a predator-prey dynamics with two state variables (similar to platform buyer and seller side) and Figure 4. the behaviour of this system over time as predators or preys overshoot periodically.

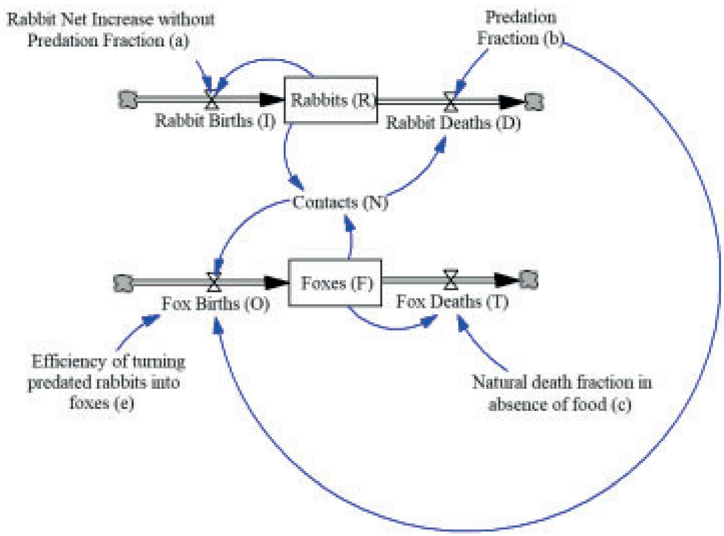

Figure 3: The archetype of a prey-predator model to illustrate simulation and behaviour

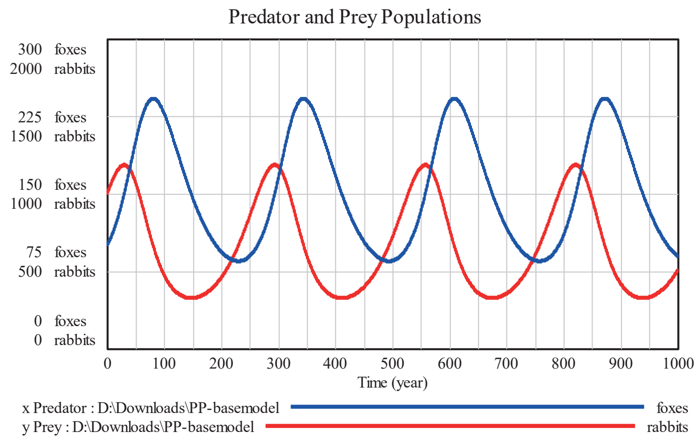

Figure 4: The results of running the prey-predator system dynamics model

Results of platform simulations show similar patterns using Figure 5. as an illustration. Casey and Töyli [15] were simulating platforms with vendors and users – lines 2 and 4 representing vendors; 1 and 3 representing users – at the two sides. The flat curves at the lower part – when 1 and 2 runs together – represent the scenario when there is no subsidization in the platform and in this case we do not see a high level of adoption and platform penetration. When there is subsidization, however, shown in the upper part with the growing curves of 3 and 4, we witness a quick upscale in both numbers of vendors and users. Vendors appear quicker, given that the model has a higher subsidy for the users given that vendors have a higher interest in generating the saturation in the platform, Similar strategy applies for public portals where there is higher interest for the government to generate user participation – so we can accept similar patterns of behaviour in that setting.

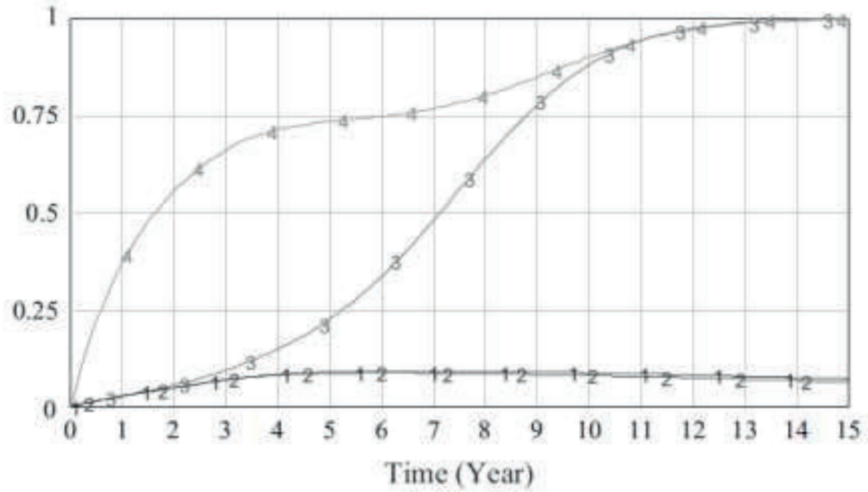

Figure 5: System dynamics simulation on a two-sided market in Casey and Töyli [15]

5. Conclusion and Summary

The microeconomic theory of two-sided markets or platforms might be successfully used to model public or government portals which intend to generate a critical mass of citizens on one side, and a large number of services and agencies on the other. The concept of single-homing monopoly platforms describe the problem of how cross-group externality occurs, and how maximum value of the platform can be achieved.

By using the dynamic model of platforms and combining it with system dynamic simulation, we have also shown that different scenarios and strategies might be tested, how to generate network effects for generating participation. This concept can improve and support government portals´ deployment as well by using the terminologies and concepts of platform economics.

6. Acknowledgement

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