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AGENT-BASED MODELLING AND SIMULATION OF THE SOFTWARE MARKET, INCLUDING OPEN SOURCE VENDORS

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ABSTRACT

In recent years, the software market has undergone profound changes. The power balance between software firms and customers is heavily changing. The contractual power of customers is increasing and the firms must take it into account.

The software appears overpriced, customers' willingness to pay is reducing, and consequently vendors are providing different pricing models for software, including terms licensing, software-as-a-service and commercial open source software. The aim of this paper is to show that a simulation-based approach to analyze the software market is viable. Therefore, in this work a business model is proposed to analyze and study how the purchase preferences of customers can modify future scenarios in the software market. We analyzed the competition among proprietary and open source software firms, but the model can be customized to study other kind of markets, and several other assumptions can be made for studying their implications to the software business.

The better way to obtain operational savings seems to be that to shift to the use of open source software, obtaining in this way all the benefits of this software typology: lower costs, greater adherence to open standards, more choice of vendor and service supplier, no vendor lock-in and flexible incremental architectures.

Keywords: Free/Libre Open Source Software, software business, software market simulation, market strategy.

INTRODUCTION

In recent years, the power balance between software vendors and enterprise users is profoundly changing. Customers do not agree anymore to pay high fees for a perpetual license [5]. According to a Gartner survey [18], the number of firms using open source software is increasing. This survey was conducted on 547 companies in the summer of 2010 to analyze software usage trends. Almost a quarter of respondents said they were turning to open source software not only to save money, but rather to obtain a competitive advantage in the market.

Open source applications have long been used only for basic infrastructure software. Now, firms are adopting open source applications because they believe they will support their business activities better. They are realizing that they can customize the code to satisfy their needs by themselves, without paying a commercial vendor to do it, and that customizing the code by themselves means gaining major competitive advantages with respect to their adversaries.

In this paper a business model is proposed for analyzing and studying the future scenarios in the software market. Moreover the proposed model could be used as tool by the project managers to analyze how their investments or their pricing mechanism might facilitate or hinder the conquest of big market share. The model compares and analyzes two different typologies of firms, those producing proprietary software and those producing open source software, but the model can easily modified to study only one of them.

This work builds on many other papers written on the subject. Among others, we quote the papers by Mustonen [12], [13], Bonaccorsi et al. [1], Bitzer et al. [6], [7], Leppämäki et al. [11], Lin [9], Economides et al. [14], and Cocco et al.[10] .

RELATED WORK

In this paper we propose a business model that follows and complements many other models appeared on the subject. However our work differ by them in many facets. Bonaccorsi et al. [1] proposed a simulation model in order to identify the relevant factors in the diffusion of Open Source, modeling the adoption decision of heterogeneous interacting agents.

Lihui Lin in [9], studies how users' skill and network effects may influence the software market, characterized by proprietary firms, and open source software firms.

Bitzer et al. [8] analyzed the influence of entry and competition of open source software on innovation and technological progress in software markets. They proposed a simple framework to examine a market structure where software producers compete in technology rather than in price or quantities.

Economides et al. [14] compare industry structures based on an open source platform with those based on a proprietary platform, analyzing the competition and the industrial implication in terms of pricing, sales, profitability, and social welfare.

The work of Mustonen [12] explains the simultaneous existence of commercial alternatives to copy left programs and why commercial alternatives to copy left programs may not exist.

Another work that appears on the subject is by Cocco et al. [10], where the authors analyzed the influence of FLOSS firms in the market software, nowadays mostly dominated by large proprietary firms.

In the end we cite the research papers that gave specific and precious insights to develop our model. They are the works by Haruvy et al. [4], Gosh [15], that suggested some variables of our model, Bulcholtz [2], YankeeGroup [19] and Sugar provider [17] that suggested the orders of magnitude of the prices of the different software solutions. The first work [4] examines a model in a monopoly setting where open source code is free but complements another product sold commercially. The authors characterize the price, quality, and hiring paths for the firms under both the open source and closed source models. The optimal decision on opening the source depends on the importance of user contributions, on wages and on the effectiveness of in-house developers.

The second work [15] studies instead the role of Free Libre Open Source Software (FLOSS) in the economy, its direct impact on the ICT sector, and its indirect impact on the ICT-related sector. We used the software product quality definition of the former paper, and the human capital definition of the latter. Starting from the many insights that came from the works above cited, we draw a model to study and analyze the competition between vendors, which is described the next sections.

THE MODEL

In this section we present a business model to analyze and study future scenarios in the software market.

This model is a simplification of reality, but it is indeed not so simple. Many simplifications have been done, but the model is complex for making it as much as possible realistic.

We modeled a software market where proprietary software firms and open source software firms compete, and analyzed market trends, in particular with reference to variation of customers' purchase preferences.

The modeled agents are: enterprise customers, proprietary software firms (PROPS firm), and Free Libre Open Source Software firms (FLOSS firms). The products in the market are substitutable, and are divided in primary and secondary products. Substitutable goods are goods that meet the same needs, have the same functionalities, but differ for example in quality and price.

With primary products we mean vertical software products, while with secondary products we mean assistance, customization, consultancy, and maintenance services associated with the use of the primary product.

The secondary product is complementary to the primary, so the primary purchase cannot be separated from the acquisition of the secondary one, although they may be purchased from different companies.

Each firm has a constant number of developers, a fraction of them work at the primary product, the remaining part work at the secondary product.

Each PROPS company produces the primary product or the secondary product, or both; and these products are both commercial. On the contrary, FLOSS companies associate each other to produce only one primary product, and each firm develops a secondary product separately. The primary product is distributed for free, while the secondary products are commercial products. Software products differ from each other in quality, maturity, uncertainty (in the case of FLOSS products) and cost.

The number of companies in the market varies over time; at random times, the entry of a random number of PROPS and/or FLOSS companies is observed.

Customers evaluate the purchase of a product through an utility function that takes into account all the characteristics of the products. The model above described follow that one presented in [10], but differs from it because it analyzes the competition among proprietary software firms and open source software firms with particular reference to the varying of customers' purchase preferences. In this work the customers' purchase choice is much more realistic than in [10], thanks to the use of an utility function very articulated that takes into account numerous variables.

PROPS Firms and Products

Every PROPS firm is characterized by its initial capital. It works alone, and develops its own products, which are characterized by quality $Q_{p,s}(t)$, maturity $M_{p,s}(t)$ and price $C_{p,s}(t)$. The primary product is characterized by a price equal to $C_p(t)$, paid by the customer at the moment of the purchase. The secondary product is characterized by a price equal to $C_s(t)$, paid monthly by its users.

Quality is defined as in the work by Haruvy, Sethi and Zhou [4], and human capital as in the economic model proposed by Ghosh [15] .

The quality of PROPS products at step t, therefore, is defined as:

$$\frac{dQ_i}{dt} = h_i(t)N_i - \partial Q_i \tag{1}$$

N_i: is the number of developers of i-th firm, who work for the primary and/or the secondary product;
δ: is the quality depreciation rate;
h: is the human capital per capita at time t; it is equal to the productivity per capita, and is given by:

$$h_i(t) = h\_i(t-1) + [\pi * u * h(t-1)]^{\gamma} * [C_{ICT/PerCapite,i}(t)]^{(1-\gamma)} \tag{2}$$

π_i: is a constant parameter reflecting the productivity of the human capital accumulation process;
u: is the fraction of time spent on human capital formation h;
γ: weighs the fraction of human and ICT capital in human capital accumulation process;
C_{ICT}: is the ICT-capital stock per capita;

Finally, a Maturity M(t) is associated to every product. With this quantity we model product maturity, which increases proportionally to human capital, and to product life time.

Each firm invests in ICT-capital to increase the productivity of its developers, and this will consequently cause an increase of quality, and of the product price.

The initial product is updated for i-th firm, through investments in ICT capital, at time intervals $\Delta_{Props,i}$.

A firm invests in non-ICT capital only to pay its developers' wages. Of course, companies invest in ICT capital and non-ICT capital only when their budget allows it. When the budget becomes negative, the company has the possibility to request a bank loan, at the risk to go bankrupt when its debt exceeds its initial capital. In the event of bankruptcy, the customers of the ousted firm are distributed to the other companies and the number of companies in the market decreases by one.

FLOSS Firms and Products

FLOSS companies in the market associate to produce a unique primary software product, while each company produces the secondary product by itself.

FLOSS companies may produce both the primary and the secondary products, or they may only develop the secondary product. These products differ in quality $Q_{p,s}(t)$, maturity $M_{p,s}(t)$, price $C_{p,s}(t)$ and uncertainty $U_{p,s}(t)$. The primary product is freely distributed, whereas the secondary products are commercial products, characterized by a cost C_s (t) paid monthly by users. Only the primary product equations are listed below, because the equations describing secondary products are similar to those of the PROPS case.

$$\frac{dQ_{p,i}}{dt} = \alpha(t) * m(t) * \lambda_m(t) + \sum_{i=0}^{N_{FLOSSf}} \lambda_q h_i(t) N_{p,i} - \delta Q_{p,i} \quad (3)$$

α: is the involvement level of the open source user community;
m(t): is the size of the open source community at the time t;
λ_q: are the parameters that limit the quality of the primary FLOSS product, with respect to the sum of contributions to the project of all FLOSS firms;
λ_m: is the fraction of the whole community that contributes to product development.

Note that equation 3 differs from the equation presented in [4] because Haruvy et al. take into account the contributions of all FLOSS firms and of the whole open source community to the Floss primary product development.

Two characteristics are further associated to each FLOSS product. They are product maturity M(t) and the uncertainty associated to the future services of the FLOSS, U(t). The first term models product maturity and is directly proportional to the human capital in the company and to the lifetime of the product. The second term models the uncertainty in the future support services of the open source software. In fact, because of the lack of legal responsibility in the case of open source software, the customers do not feel legally protected, and sometimes refuse to purchase FLOSS products. This term is inversely proportional to the number of customers and to the profits of the FLOSS firm by which users want to buy the product.

Each FLOSS company can invest in ICT capital and non-ICT capital; the mechanism coincides with that described for the proprietary companies.

Also the FLOSS firms release updated products at regular intervals, whose values are greater than that of the proprietary firms. The updates are free, and customers may decide freely to update or not to update their products. As in the PROPS case, the firms can make investments only if their budget allows them to.

The mechanism of funding request and the mechanism of failure is the same as for proprietary companies.

Investments and Pricing Method

Each firm enters the market with an initial investment $C_{initial,i}$, depending on the number of employees, that does not vary during the simulation.

In order to enter the market, every firm invests at the initial time t=0, a fraction β of its initial capital $C_{initial,i}$.

$$C_i(t=0) = C_{initial} * \beta_i \quad (4)$$

At regular intervals the firms invest in ICT capital for updating their products; the capital amount invested is a random normal variable depending on the company profits.

$$C_{i,ICT}(t) \in [0, \mu_i(t) * \mathrm{Pr}\,ofit(t-1)] \quad (5)$$

The companies invest small amounts of capital monthly to maintain product quality to an acceptable level. This quantity is proportional to the last amount of ICT capital invested for updating the product.

$$C_{i,ICT,monthly}(t) = r_i * C_{i,ICT} \quad (6)$$

As mentioned in the previous section, the companies can make a new investment only if the budget allows it.

If the company is at a loss and cannot make the investments planned, it can apply for funding.

The value of the bank loan is equal to the difference between the profit and the capital to invest at time t. For each new loan request, the time at which to return the loan and its interest rate are calculated.

The pricing method adopted by both types of firms takes into account the investments made by the company, the number of companies, the total number of customers in the market, and ultimately the profit a firm wants to obtain. In particular, the price is directly proportional to the investments done, to the total number of the firms in the market, and is inversely proportional to the total number of users in the market.

Customers

The number of customers in the market varies during the simulation period. At random intervals a random number of customers can enter or exit the market.

Each customer has her own portfolio and her own skill level θ, both variable over time. In fact a customer who uses a software product enhances her experience and becomes more familiar with software products: it can be assumed that skill level is not constant over time, but grows.

The mechanism by which a user chooses which product to buy works in the following way. Initially, at time t=0, the customer evaluates all products on the market, and chooses one primary product and one secondary product using an utility function. During the simulation, at each time step a random number of users is drawn to revaluate whether the product owned is the most convenient choice.

Moreover, each time a new firm enter the market, a number of users equal to one third of the total user number is drawn to evaluate the new products in the market.

A user drawn to consider the purchase of a new product compares its current utility function $UF_{j,i}$ to the utility functions associated with the other products on the market, and chooses the products with the maximum utility function.

In general, the utility function indicates the subjective evaluation about the attitude of a good or of a service to meet an economic need. In our case it depends on different factors: quality, cost, maturity, uncertainty relating to future support services in FLOSS, switching costs ρ and finally a normal variable χ.

For instance, for j-th customer and the primary product of the i-th firm, it is defined as:

$$UF_{j,i}(\theta,t,\chi) = a_{1,j}(\theta,t)Q_{i,p}(t) + a_{2,j}(\theta,t)C_{i,p}(t) + a_{3,j}(\theta,t)M_{i,p}(t) + a_{4,j}(\theta,t)U_{i,p}(t) + \rho + \chi \quad (7)$$

$a_{k,j}(\theta,t)$: parameters that weigh and customize the different perception of the features of the products by the customer j-th;

$Q_{i,p}(t)$: quality of the primary product, produced by the i-th firm at time t;

$C_{i,p}(t)$: cost of the primary product, produced by the i-th firm at time t;

$M_{i,p}(t)$: maturity of the primary product, produced by the i-th firm at time t;

$U_{i,p}(t)$: uncertainty of the primary product, produced by the i-th firm at time t;

ρ : switching costs;

χ : parameter that introduces a normal noise in the utility function.

All terms in the utility function are normalized. The values of the coefficients a_j vary with the skill level θ of the users, and are initially assuming that users with low competence prefer to acquire low-cost products, and neglect the product maturity. On the other hand, we assume that expert users consider much more maturity, and quality.

Finally, users with an intermediate skill level choose the product to buy in a way that stays in the middle of the choice criterions above reported. Of course, different assumptions can be made for analyzing the market trends from diverse point of view, we proposed only an example of the many assumptions that can be made.

THE SIMULATIONS

An efficient Java simulator was written to simulate the model presented in the previous section, in order to study the behavior of the diverse agents and the trends of the software market.

Modeling the software market in a realistic is very complex, and the resulting mathematical model is characterized by an intricate system of equations that connect the diverse agents and the diverse products in the market. So, a firm's survival depends on many variables closely linked to each other.

We simulated firms producing vertical software application. Remember that we model three kinds of PROPS firms – firms producing only the primary product (the software application), firm producing only the secondary product (the customization and maintenance services), and firms producing both; and two kinds of FLOSS firms - firm producing only the secondary product (the customization and maintenance services), and firms producing both. We call “PP”, “PS”, “P”, “FS” and “F” these kinds of firms, respectively.

We set the parameters of our model following the considerations presented in the work [3]. In that work, the authors affirmed that the maintenance costs for software products are a percentage of the license cost, varying between 15 and 23% of the software cost. So, the relative prices of the primary and the secondary products satisfy these percentage.

Regarding the price of primary PROPS products, it is computed in such a way that the firms have to cover their costs – plus a 20 percent markup - given the number of their customers. The initial capital of firms – and hence the price of their products – may vary of even more than one order of magnitude; this is consistent with the fact that the price of products in the same vertical segment was empirically found to vary of more than one order of magnitude [17].

The prices of the upgrades of software products, depend on how much customization and integration of the application is made to the software application. We assumed, as in [19], that these prices are included in the secondary price. In Tables 1 and 2 we report the parameters used for performing the simulations; they are closely related to the firm's ability to survive in the market.

The reported values are taken from the literature, by analyzing market data, and by using our experience in software engineering. They have to be considered a first attempt to build such a complex model, and to verify its consistency. The proposed model regards an ideal software market, where at the initial time all companies enter the market, each with their offer, and all the users make their purchasing decisions. Only afterwards customers and firms operate according to more realistic strategies.

The simulations executed were designed to analyze the influence of FLOSS companies on the software market, and to assess whether there are conditions under which FLOSS companies can compete with PROPS companies.

In particular, we analyzed the competition among the big PROPS firms and small local FLOSS firms. The latter are characterized by a number of developers smaller than those of the PROPS firms, and consequently their initial capital and their investments are smaller than PROPS one. In Table 2 we report the values of the initial capital and the number of developers for every type of company, PROPS or FLOSS.

Table 1: Parameter Values of the Proposed Model

Parameters	Value
Number of firms at initial time t=0:	10
N_f number of firms entering the market, at intervals $\Delta_{P,F,i}$:	Random number in the range [3,10]
N_C Number of users at initial time t=0:	30,000
Number of users drawn to consider the purchase of a new product:	$N_C/3$
$\theta_j(t)$: (in equation 7)	In the range [1,4]
δ: (in equation 1 and 3)	Δ =0.03 (Haruvy, Sethi and Zhou [4])
π_i (in equation 2):	π_i =0.025, (Ghosh, p.237 [15])
u (in equation 2):	U =0.1 , (Ghosh, p.237 [15])
γ (in equation 2):	Γ =0.9 , (Ghosh, p.237 [15])
β_i (in equation 4):	Characterized by a normal distribution with average μ= 0.9 and standard deviation σ=0.033.
μ_i (in equation 5):	Characterized by a normal distribution with average μ=0.6 and standard deviation σ=0.016.
r_i (in equation 6)	Characterized by a normal distribution with average μ= 0.0002 and standard deviation σ=0.000033.

Table 2: Parameter Values of the Proposed Model- Parameters depending on the kind of firm

Parameters	PROPS Vendors	FLOSS Vendors
Number of developers. It is constant over time.	Characterized by a normal distribution with average μ=135 and standard deviation σ=22 for OP firms that produce both primary and secondary products; and with average μ= 85 and standard deviation σ=5 for firms that produce only one product, primary or secondary	Characterized by a normal distribution with average μ=40 and standard deviation σ=10 for COS firms that produce both the products; and with average μ=30 and standard deviation σ=6 for firms that produce only one product.
Initial capital available for each company:	it is equal to 50,000.00 per employee for firms with more than 50 employees, while it is equal to 40,000.00 per employee for firms with fewer than 50 employees.	
$\Delta_{P,F,i}$ intervals when new firms enter the system:	Characterized by a normal distribution with average μ= 36 and standard deviation σ=4	Characterized by a normal distribution with average μ= 15 and standard deviation σ=1.
α (in equation 3):		Characterized by a normal distribution with average μ= 0.4 and standard deviation σ=0.033.
λ_q (in equation 3):		Characterized by a normal distribution with average μ=[1/(A-1)+1/(A+1)]*1/2 and standard deviation σ=[1/(A-1)-1/(A+1)]*1/6, with *A* equal to the total number of FLOSS Firms
λ_m (in equation 3):		Characterized by a normal distribution with average μ=0.035 and standard deviation σ=0.005.

The model is studied for a period of time equal to 100 months; the unitary time step used by our simulator corresponds to one month. The initial number of users is equal to 30,000, and the initial number of firms is equal to 10. We analyzed the model sensitivity to the parameter values related to the purchase choices of users. To this purpose, we ran three simulation sets.

In the *first set*, that we call *A*, the model was run giving to a_j coefficients values that are consistent with the considerations reported in the Section entitled Customers. In the *second set, B*, the model was run giving to a_j coefficients values that respect the considerations made by Laurie Wurster, Galen Gruman et al. [5], [18], who state that enterprise customers using open source software are increasing.

In the *set A* we considered an entry probability for PROPS firms higher than that of FLOSS firms, as happens in reality. We considered an entry probability equal to 0.7 for PROPS firms, and equal to 0.3 for FLOSS firms. In *set B,* instead, we set up the entry probability equal to 0.6 for PROPS firms, and equal to 0.4 for FLOSS firms, for studying how the market trends could change in response to an increase of the number of FLOSS firms.

The *set B* was repeated tree times with different a_j coefficient values, set so that the choice of the users was more and more towards the FLOSS products.

Finally the parameters in the *third set, C*, are similar to *set B,* varying the coefficient λ_m, that is the fraction of the open source community involved in the primary FLOSS product development.

For clarity, in Table 3 we report the diverse cases analyzed, and we associate to each of them a capital letter and possibly a number for identifying them. In Table 4 we report the value of the entry probability for the five type of firms modeled, in the various cases.

Table 3: Simulation Set

	1st Set A	2nd Set B	3rd Set C
Set Name	A	B B1 B2	C C1

Table 4: Entry Probability of firms

Firms	Entry Probability: Set A and C	Entry Probability: Set B
P	0.2161	0.1957
PP	0.2161	0.1919
PS	0.2839	0.2249
F	0.0882	0.1037
FS	0.1957	0.2839

The entry probability values reflect the need of having in the former case a higher number of PROPS firms with respect to FLOSS firms, and in the latter case a number of PROPS firms almost equal to that of FLOSS firms.

We denote firms that produce the primary and secondary product, with P in the PROPS case, and with F in the FLOSS case. We denote with PS and FS, respectively in PROPS and FLOSS case firms that produce only secondary product, and with PP PROPS firms that produce the only the primary product.

To assess the robustness of our model, we also applied the Monte Carlo approach for all simulation sets, repeating 20 times with the same initial conditions, but with different seeds of the random number generator for each case.

Simulation of the Model

We report some results obtained in the simulation *set B*.

We analyzed the competition among PROPS firms and FLOSS firms when in the initial time t=0, 30,000 users and 10 firms are present in the market. Overall, the total number of firm that entered in the market is 21. The firms that survived are 9, 3 of them being FLOSS firms.

In Table 5 and 6 the number of customers of the survived firms is reported. These results highlight that the firms having the bigger market share are the PROPS firms.

These firms conquest at the end of the simulation a market share for the primary product equal to 61 percent, and equal to 85 percent for the secondary product. The FLOSS firms, conversely, get a market share equal to 39 percent for the primary product and equal to 15 percent for the secondary product.

Table 5: Result analysis for the primary product, set B

Firm survived	Entry Time	Primary Customers
P	1	4,405
P	1	4,191
PP	1	6,366
F	1	5,909
PP	28	3,243
P	42	5,787

Table 6: Result analysis for the secondary product, set B

Firm survived	Entry Time	Secondary Customers
P	1	5,943
P	1	6,185
PS	1	7,107
PS	1	6,773
F	1	993
F	42	1,031
FS	70	1,867

Figures 1 and 2 report the number of customers of the various firms as a function of time. Regarding the firms that produce the primary product, it is worth noting the behavior of the firm that dominates the market from time 10 to time 70, and then. It is distinguished for having a higher number of customers than others. Others three firms were able to stay in the market, but with smaller market share. All other firms went bankrupt within 14 months. New entrants often fail in a few months. Two other firms, entering at months 38 and 54, were able to survive, the latter even being able to become co-leader of the market in 20 months. The firm with the most market share maintains this feature until about time 70 when its market share decreases, and became similar to that of the others firms. Only one FLOSS firms is able to survive. The market of the secondary product shows a rich behavior, too as shown in Fig.2. In this case, a stable oligopoly of four PROPS firms is formed, that hold the biggest market share. Only one FLOSS firm is able to survive since the beginning, and is followed by two more FLOSS firms entered afterwards, taking advantage of the FLOSS business model. Clearly, the presented results are valid for a specific set of parameter settings, and are reported to show the potentialities of our model.

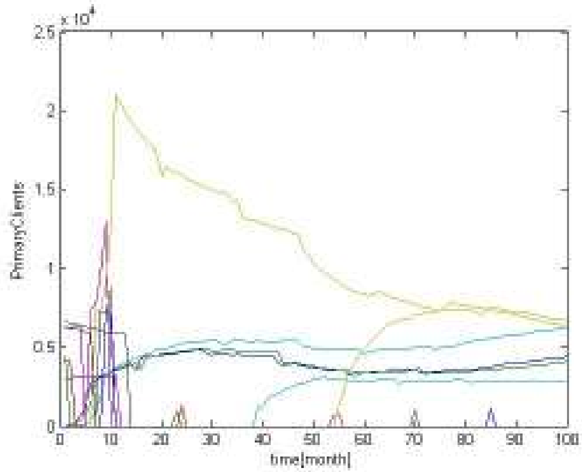

Figure 1: Customers of the firms that produce the primary product

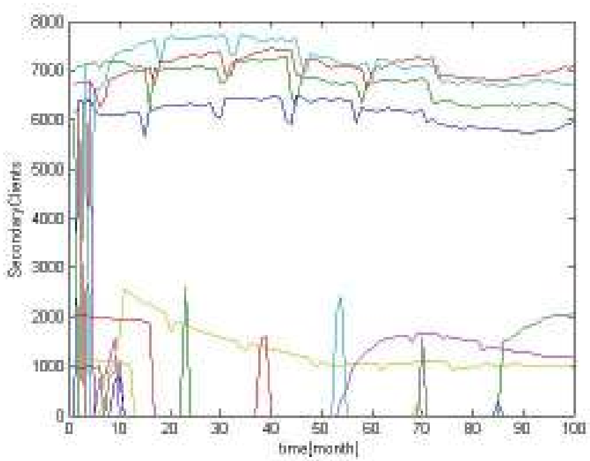

Figure 2: Customers of the firms that produce the secondary product

Robustness Analysis of the Model

In this section we report the results of the Monte Carlo analysis made on all the simulation sets presented in the previous subsections.

Each analysis was performed by simulating 20 times each model with different seeds of the random generator.

The results of the Monte Carlo analysis related to the simulation of type *A*, show that PROPS firms conquest big market share, whereas all FLOSS firms are consistently ousted in all simulations. In Table 7 we report the percentiles of the distribution of customers that buy the primary products in this case. In simulation *B,* instead, according with the increase in the number of FLOSS firms, we observe that these are able to compete with PROPS firms and obtain enough big market share. The FLOSS firms associate for producing only one primary product, and so if their number increases, the quality of the product increases and consequently the number of customers grows too.

Table 7: Monte Carlo Analysis Results: percentiles of customer' distribution buying the primary product either from PROPS firms or FLOSS firms, in type A simulations.

Percentiles	A	
	PROPS	FLOSS
$P_{0.25}$	4,573	0
$P_{0.50}$	7,191	0
$P_{0.75}$	9,473	0

Of course the fact that the FLOSS primary product is freely distributed plays an important role in the acquisition of bigger market share by FLOSS firms.

The simulations belonging to the *second set*, *B*, were performed by setting the a_j coefficients to values derived from the considerations made in the works [5] and [18]. We carried out 3 simulation sets: *B*, *B1* and *B2*. In each set the a_j coefficient values varied with the aim to direct the user' purchase preference more and more toward FLOSS primary product.

In Table 8 we report the percentiles of the distribution of customers that buy the primary product, either from PROPS or FLOSS firms. We can notice that the number of FLOSS primary product customers grows more and more going from *set B* to *set B2*, according to the values given to a_j coefficients.

A parameter that heavily influences the results of our simulations is λ_m. We remember that this parameter indicates the fraction of Open Source community that contributes to FLOSS primary product development. To analyze the influence of parameter λ_m on our model, we performed further studies, in particular the cases *C*, and *C1* were carried out. These cases share with *set B* the parameter values, except for the value of the λ_m parameter, that varies in the range [0.05, 0.08], and [0.1,0.08], respectively for set *C*, and *C1* . In all the others cases analyzed this parameter varied in the range [0.02, 0.05], as reported in Table 2.

Table 8: Monte Carlo Analysis Results: percentiles of customer' distribution buying the primary product either from PROPS firms or FLOSS firms, in type B simulations.

Percentiles	B		B1		B2	
	FLOSS	PROPS	FLOSS	PROPS	FLOSS	PROPS
$P_{0.25}$	3,359	5,250	2,687	5,433	3,482	4,924
$P_{0.50}$	4.250	6,352	3,537	6,054	4,888	6,083
$P_{0.75}$	5,210	9,265	5,642	6,375	7,391	8,662

The percentiles about distributions of customers that buy primary products either from PROPS firms or FLOSS firms, are reported in Table 9. The results reported in Table 8 and 9 show that, if the number of FLOSS firms grows, the contribute of Open Source Community can became irrelevant and the FLOSS firms are able to survive also with a small community contribution.

Table 9: Monte Carlo Analysis Results: percentiles of customer' distribution buying the primary product either from PROPS firms or FLOSS firms, in type C simulations.

Percentiles	C		C1	
	FLOSS	PROPS	FLOSS	PROPS
$P_{0.25}$	2,916	8,857	2,449	8,626
$P_{0.50}$	3,393	9,792	2,959	9,282
$P_{0.75}$	4,167	10,457	4,607	11,295

In Table 10, 11 and 12 we report the percentiles of the distribution of secondary product customers of every set of simulations carried out. These data highlight that the distribution of customers that buy the secondary product, changes according with the assumption done for each case, as described above. All the results above reported show that the software market can be analyzed using simulation-based approach, provide that the parameters' values are sound and properly tuned. They also show how the model can be used and tuned to study time trends of different market segments.

Table 10: Monte Carlo Analysis Results: percentiles of customer' distribution buying the secondary product either from PROPS firms or FLOSS firms, in type A simulations.

Percentiles	A	
	FLOSS	PROPS
$P_{0.25}$	3,708	0
$P_{0.50}$	6,654	0
$P_{0.75}$	7,593	0

Table 11: Monte Carlo Analysis Results: percentiles of customer' distribution buying the secondary product either from PROPS firms or FLOSS firms, in type B simulations.

Percentiles	B		B1		B2	
	FLOSS	PROPS	FLOSS	PROPS	FLOSS	PROPS
$P_{0.25}$	3,879	453	5,103	589	5,132	663
$P_{0.50}$	4,856	779	5,920	815	6,166	776
$P_{0.75}$	6,077	1,455	6,534	1,480	6,548	1,132

Table 12: Monte Carlo Analysis Results: percentiles of customer' distribution buying the secondary product either from PROPS firms or FLOSS firms, in type C simulations.

Percentiles	C		C1	
	FLOSS	PROPS	FLOSS	PROPS
$P_{0.25}$	4,582	884	4,845	916
$P_{0.50}$	5,715	1,296	5,880	1,166
$P_{0.75}$	6,626	1,687	6,624	1,733

CONCLUSIONS AND FUTURE WORK

Our model -as every simulation model - is a simplification of the real world. It represents each agent in an ideal way, and is based on several parameters, generally difficult to estimate. The aim of the presented work, however, is to show that a simulation-based approach to analyze the software market is viable.

Modeling the software market so that the model is as realistic as possible was a very difficult work, because the mathematical model obtained is very complex, characterized by an intricate system of equations, with many parameters, often difficult to estimate.

To this purpose, we estimated the values of these parameters using data found in the literature and analyzing market data. Unfortunately, the parameters values and the number of equations built on scientific knowledge, or on market data analysis are only a few.

To our knowledge, this is the first time that software market has been modeled detailing investment politics of firms, pricing politics of products and purchase preferences of customers. For this reason, building the model on existing scientific knowledge has not been very simple. Our work has been carried out under some limiting assumptions that could threaten its validity. We proposed a set of equations for modeling enterprise investments, pricing of products, and the purchase preferences of customers, according to our experience. Lack of experimental data to initialize or validate simulations clearly limits the validity of our model, and for this reason our future main objective will be to validate the model using real enterprise data, to demonstrate that the proposed work can be used to study the software market and possibly to make risk analysis and strategic forecasts.

In spite of the difficulties to model the software market, and to assign the values to the parameters of the various equations, the results obtained seem to follow the real trends of the software market.

The overall model might be further validated comparing time trends of prices to some data reported in the literature. The price trends obtained from our simulations are in fact in accordance with SIIA [16] and CloudOne [3] White Papers. The first paper states that: *"The biggest TCO factor of premise-based traditional software applications is the cost of the ongoing people resources that are needed to monitor, maintain and upgrade the application and to provide training and support to the end-user base. These costs are not quoted as part of the cost of deploying the traditional software application and depending on the application, can be between 50 and 85% of the total cost of ownership for the application"* (p.19).

For these percentages the authors refer to Gartner Inc, a global analyst firm tracking the high tech market, estimating *"that more than 75% of the IT budget is spent just maintaining and running existing systems and software infrastructure"* .

It is possible also to refer to IDC, another global analyst firm, which came to a similar conclusion when it did an analysis of the web conferencing industry. It determined that *"hidden personnel costs can be as high as 70% of the total cost to run premise-based conferencing software"*.

The same conclusion are also achieved in the second cited paper, that performs an analysis about the components of the Total Cost of Ownership for On-Premise software versus On-Demand software, with reference to a white paper of Yankee Group [19].

Our results confirm what is reported in these works. The primary product price is only a small part of the total cost of ownership. Indeed, it is only a small percentage of the price paid by customers to have the secondary product.

So, it is possible to conclude that, under this respect, the price trends follow the real trends of the software market.

Clearly, further research is needed to improve the model, making it more realistic by studying which parameters of the model have the larger effect on the results. Our future main goal is that of validating the model using real enterprise data.

Further studies are under work to assess how our model behaves varying key parameters about firms' costs and attitude to invest, and customers' utility function.

We will study and analyze also new pricing trends and their impact on software market.

In particular, we will give special attention to software-as-a-service, that is nowadays a phenomenon that software vendors cannot neglect.

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