A comparative survey of economic models for software product lines

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***Abstract*—Software product line engineering aims at achieving systematic reuse by exploiting commonalities among related products in order to reduce cost and time-to-market. Before adopting this approach, organizations are likely to estimate the benefits they can expect to achieve and the level of investment required to transition to product line engineering. Several economic models and analysis approaches have been developed in order to help make a sound business case. There is a need to review the existing approaches in order to better understand the overall landscape of economic models. To this objective, this paper provides an overview of some existing economic models and discusses important issues and directions in product line economic modeling.**

Keywords-software product lines, economic models

I. INTRODUCTION

As benefits of Software Product Line Engineering (SPLE) are becoming evident, more and more companies are trying to adopt this approach. Moving from a traditional engineering approach to SPLE requires many technical, financial, organizational, process and market considerations. However, most important are financial or economic aspects since organizations adopt new technology and practices to maximize their productivity and hence profitability. The argument for transition towards SPLE is based on the promises of economic benefits, not on the promises of improved functions which can be achieved even with a single system development approach [1]. There are numerous success stories, which suggest economic and strategic benefits of SPLE [2]. Though such reports highlight the gains, there can also be significant cost and risk involved [3, 4]. Organizations, therefore, demand financial justifications for SPLE.

Economic models can help organizations to make fundamental go/no-go decisions towards SPLE. Many economic models have been proposed by the community as a basis to justify such decisions. A model which can help predict the return on investment (ROI) of SPLE activities significantly supports a rational decision making. Estimation of ROI is based on cost models, which exist at various levels of details. A model that estimates cost on a detailed level is COCOMO-II [5], which focuses on single system development. Some models estimate cost and ROI on a rather abstract level, but at the cost of accuracy [6]. These generic models are helpful in quick assessments of go/no-go decisions for adopting SPLE. Several such models and economic analysis approaches have been proposed for SPLE. These approaches are based on earlier work in software reuse economics. SPLE introduces new assumptions and cost drivers, which have not been captured by most of the reuse models. Each economic model formulates certain aspects of Software Product Line (SPL) economics while excluding others. A comparative review of these models is expected to facilitate practitioners in deciding which model(s) can best serve their needs. Towards this goal, we summarize a few major efforts in this paper. We identify important issues in SPL economic modeling, and report on unique characteristics of the analyzed approaches.

Our survey is structured as follows: Section II discusses a few similar efforts in reuse economics, Section III briefly discusses our approach, Section IV provides a comparative view of the economic models, echoes some thoughts and possible research directions, Section V concludes our presentation.

II. RELATED WORK

There has not been much effort to review, appraise, and compare economic models with a specific focus on SPLE (a notable exception being [1]). However, economic models of software reuse have extensively been surveyed in the past. For example, Bandinelli and Sagarduy [7] provided a summary of the attitudes of the reuse economic models towards process issues. Poulin [8] also provided a review of some models. Lim [9] compared 17 economic models using a common lexicon to translate model parameters for better comparison and to reveal statistical aspects about model parameters. Wiles [10] reported a comprehensive survey of 25 economic models, and provided a framework for model translation.

Besides, there have been efforts to categorize economic models. Frakes and Terry [11] defined a set of categories for reuse models in general, and classified reuse cost-benefit analysis models into three categories: cost productivity models, quality of investment, and business reuse metrics. Nazareth and Rothenberger [12] characterized the models as metric-based and cost-based. Mili et al. [13] based their classification on several different aspects of the reuse economic models such as investment cycle, economic functions, cost factors, structure of reuse organization, scope, hypothesis, and viewpoint.

III. APPROACH

A number of economic models and analyses approaches for SPLE have been proposed since last decade. We have considered a few major efforts for initial comparisons in order to identify issues which could arise in later detailed analysis and to further explore the criterion for in depth comparison. This paper presents results of our initial comparison with 12 different economic models listed in Table I.

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Since the selected models are heterogeneous in terms of their main characteristics and goals, a comparison among the models is rather difficult. One possible way of comparison is to use model translation. Lim defined a common lexicon to compare different models [9]. Wiles provided a common framework for model translation by identifying benefits and costs [10]. While being in general useful, this approach is not sufficient in our case as we have identified a mix of qualitative and quantitative models with widely varying analysis techniques and some models must be more regarded as frameworks in their own right. Another approach is that of Mili et al. [13] who suggest that economic models differ in various perspectives. This approach is useful to reveal important aspects considered in the model. We therefore attempt to expose some of the features of the SPL economic models from various perspectives which have been highlighted by Schmid [1] and Mili et al. [13]. We base our comparison in next section on these perspectives, which are:

- *Scope*: How much coverage in a SPL life cycle does the model support? Some models target pre-adoption estimation and analysis for strong business cases, while others aim to support the whole lifecycle.
- *Types of Analysis*: Whether the model supports cost estimation, investment analysis or both?
- *Economic function*: What functions does it utilize to judge economic worthiness of decisions?
- *Underlying model*: On which earlier developed model(s) the current model extends or is based on?
- *Viewpoint*: What viewpoint(s) the model supports? Some models take 'corporate' viewpoint; they focus on cost-benefits of the whole corporation. Others take 'system' viewpoint, which only considers costs-benefits applied to a particular system. A more narrow viewpoint is 'subsystem' viewpoint
- *Scenario*: Are there any predefined scenarios which the model supports specifically?
- *Market Attributes*: Does the model consider the impact of market attributes [1] on the value of SPL?
- *Cost factors*: What are the important cost factors?
- *Risk adjustment*: Does the model support to take risks into account when computing time-value of money?

IV. Comparison and Discussion

A. Analysis

Table I summarize the results and provide a comparative view. Some observations are evident:

1) Scope

Though all of the models can be utilized in deciding about product line transition, only half of the models target the whole institutionalization process, and provide support for cost-benefit estimation of maintenance and evolution activities in certain aspects.

2) Type of Analysis

Eight out of 11 models provide cost functions to estimate the cost/effort incurred in various activities in due course of product line development. Only three models consider investment analysis to enable devising strategies for maximizing returns. According to Schmid's framework [1], most models are thus first or second order models.

3) Economic function

Return on investment (ROI) is the most popular function to assess the investment outcome. However, it does not take the effect of time into account. Net preset value (NPV) estimation with discounted cash flow is mostly used to address the time value of money. One model utilizes Expected Net Present Value (ENPV).

4) Underlying model

Relatively recent models are based on or inspired by previous models, which indicates that newer models are an extension of the capabilities of underlying models. It also

TABLE I. Comparison of product line economic models

Sr	Approach	Scope	Type of Analysis	Economic function	Underlying model	Viewpoint	Scenario	Market Attr.	Cost factors	Risk adjust.
1	Withey [14]	A	IA	DTA	-	Co	No	Yes	Activity costs	Yes
2	Poulin [8]	A	CE	ROI	-	S	No	No	RCWR, RCR	No
3	Schmid [15]	LC	IA, RA	NPV, DTA	-	Co, S	Yes	Yes	Adaptive reuse, cost for reusing, dev. for reuse	Yes
4	ABC [16]	A	BC	CS, PBP	-	Co	No	No	COR, DOR	No
5	SIMPLE [17]	LC	CE	ROI	-	Co, S, SS	Yes	No	C_{org} , C_{cab} , C_{unique} , C_{reuse}	No
6	Peterson [18]	A	CE	NPV, PBP, IRR	-	Co, S	Yes	No	No. of products/components, Arch. quality, Org. size	No
7	COPLIMO [19]	LC	CE	CS	COCOMO-II	S, SS	No	No	RCWR, RCR	No
8	SoCoEMo-PLE [20, 21]	LC	CE	ROI	Mili et al., Poulin	Co, S, SS	No	No	IC, RCRW, OC, Periodic cost	No
9	Wesselius [22]	A	IA	Expected NPV	-	Co	Yes	No	Architectural, strategic scenarios	No
10	qCOPLIMO [23]	LC	CE	CS	COPLIMO, COQUALMO	S, SS	No	No	RCWR, RCR, Cost per defect, Testing effectiveness	No
11	Ganesan. [24]	A	CE	ROI	SIMPLE	Co, S	No	No	C_{org} , C_{cab} , C_{unique} , C_{reuse}	No
12	InCoME [25]	LC	CE, IA	ROI, NPV, PBP	Mili et al., SIMPLE	Co, S, SS	Yes	No	IC, Periodic cost	No

CE – Cost/effort Estimation
IA – Investment Analysis
BC – Business Case
RA – Risk Assessment

ROI - Return-On-Investment
NPV - Net Present Value
IRR - Internal Rate of Return
PBP - Payback Period
DTA - Decision Tree Analysis
CS – Cost Savings

A – Adoption
LC – Life Cycle
Co – Corporate
S – Systems
SS – Sub-systems

RCR – Relative Cost of Reuse
RCRW – Relative Cost of Writing for Reuse
IC – Investment Cost
OC – Operating Cost of the library
COR – Cost of Reuse
DOR – Degree of Reuse

indicates the maturity and applicability of underlying models.

5) Viewpoints

The majority of the models reflect more than one viewpoint in their economic analysis. The systems engineering viewpoint is most common among economic models, though few models consider the sub-system viewpoint. Ganesan et al.'s model [24] considers the multiple systems viewpoint and looks over the generations of product lines.

6) Scenario

Most of the product line economic models do not consider possible scenarios that may arise under various organizational contexts. Only SIMPLE has given a detailed list of scenarios covering construction, evolution, regeneration, and build vs. buy scenarios. The models proposed by Peterson, Nóbrega and Schmid also provided some scenarios.

7) Market Attributes

Most of the models (9 out of 11) do not consider market attributes.

8) Cost factors

Models use a wide variety of cost factors. Some models take a reuse-based perspective, while others focus on the product perspective. Some cost factors are different in both of these approaches.

9) Risk adjustment

Only two models consider risks and uncertainties in their investment analysis process. They use decision tree analysis or consider risk-adjusted discount rates to cater for the effect of risk.

B. Issues in Modeling SPL Economics

Many of the models discussed in this paper are closer to a framework for characterizing cost models than being an actual cost model. One must differentiate between models that simply look at the advantages of SPLE vs. traditional engineering and models that include the transition phase as well.

Modeling economics of SPL is a challenging task. Different models support different depth of analysis and utilize different techniques. They may produce different results under the same scenarios [26]. This is a result of different cost factors and the way costs are accumulated. Models emerge from subjective reasoning and reinforce the idea that economic models, of course, are not the perfect predictors of the future. They make specific assumptions about the external conditions and input variables, which might not always be valid in real world scenarios since no model can fully represent the dynamics of software development. Even if a model considers a large number of cost-benefit drivers, it may not provide guidance in every aspect to make the right choice among alternatives. It is difficult for an economic model to replace experience or instinct because models cannot embody the tacit knowledge as well as the intangibles such as cultural/political factors in an organization [17]

C. Need for Validation

It has been well recognized that despite the success in adopting SPL the community needs more quantitative data to support that approach [6, 15, 27, 28]. The situation has been the same for reuse economic models. Frakes & Terry [11] mentioned that several reuse cost-benefit models have been reported but none of these models are derived from data; nor have the majority of them been validated with data. Lim [9] and Wiles [10] also raised the same concern. We observed a similar trend in our review. Though some of the models ([10, 16, 18, 24, 25]) have presented industrial case studies, the methodological rigor is a big question mark. There is a clear need for many more empirical studies to validate existing models, and collect data to establish a database of cost-benefit drivers in various contexts. Confidentiality of financial data and lack of support from executives have posed major restriction to in depth empirical evaluation. Whatever data is available on the economic impact of SPLE is therefore presented at the aggregate level [28].

The obvious lack of available data for validation is one of the reasons researchers have been using simulation models. There have been a number of efforts with Monte-Carlo simulation techniques [24, 29, 30]. Though simulation approaches can be promising for sensitivity analyses, they require a sound understanding of the uncertainty in the data to define value ranges and probability distributions for the model variables, to achieve correct and useful results.

D. Future Directions

There are many open avenues for future research in the field. We briefly discuss only some of them.

The shift to product lines can yield advantages to different stakeholders at varying levels. A possible effort would be to investigate whether we can construct a framework that can guide in devising an optimal reuse strategy which can create economic incentives for all relevant stakeholders; in other words how to be able to maximize corporate ROI while keeping all relevant ROI's positive. Though there have been some efforts, most SPL economic models do not account for uncertainty. There is a need for market-oriented economic models to explicate the benefits achieved by introducing products into the market earlier. Similarly, no model captures time to market (saved by reuse), effect of process and resource constraints, organizational structure, and outsourcing.

An area that needs attention is the identification of cost drivers for asset reuse at finer levels of granularity [9]. We still lack trustworthy data to estimate how much of the cost and benefits that result from a SPL approach is captured by these models.

SPL assets are not meant to be stable forever. There is always a refresh rate, as Cohen [16] points out. Market dynamics, changing customer needs, new business policies, all impact the product line to evolve in a certain way within certain duration. New products arrive in a product line, older ones leave. Assets change, so do the level of 'ilities' they are expected to deliver. Inability of reusable artifacts to conform to the contract (either implicit or explicit) can induce problems like architectural mismatch [31], but from the current discussion stand point, it somehow reduces the economic benefits, too. It is thus important to evaluate assets from the perspective of their quality attributes, and then determine whether reuse of a particular asset will result in an economic gain or loss. Work of Ozkaya et al. [32] is an effort in this direction.

V. CONCLUSION

Understanding of SPL economics can play a significant role in the performance of SPLE. A number of economic models have been proposed to facilitate this understanding and eventually decision making. We surveyed some of the significant economic models. A detailed analysis of all existing models is part of our future work. In current scope of our review, we found that most of the models do not address important economic aspects like market considerations, risk adjustment, scenarios and viewpoint facilitation. Validation of these models is also a concern as no reliable data is available on the accuracy of the prediction of these models. We believe that it is very important that organizations understand the strengths and limitations of different economic models, which should be sought for broader insights, not absolute answers. Economic models can never be perfect, and there is always room for improvement. We summarize with a quote from the concluding remarks at the SPLC-Europe 2005 panel [26]: “Product line economic modeling is a journey, not a destination…”

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