A Financial Approach for Managing Interest in Technical Debt

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Abstract. Technical debt (TD) is a metaphor that is used by both technical and management stakeholders to acknowledge and discuss issues related to compromised design-time qualities. Until now, despite the inherent relevance of technical debt to economics, the TD community has not sufficiently exploited economic methods/models. In this paper we present a framework for managing interest in technical debt, founded on top of *Liquidity Preference,* a well-known economics theory. To tailor this theory to fit the TD context, we exploit the synthesized knowledge as presented in two recent studies. Specifically, in our framework, we discuss aspects related to technical debt interest, such as: types of TD interest, TD interest characteristics, and a proposed TD interest theory. Finally, to boost the amount of empirical studies in TD research, we propose several tentative research designs that could be used for exploring the notion of interest in technical debt practice.

Keywords: Technical debt · Architecture · Software quality · Interest

1 Introduction

The term *Technical Debt* (TD) was coined in 1992 by Ward Cunningham [8] to describe the technical compromises being made while coding, in order to speed up product delivery and meet release deadlines. Research on technical debt is currently an active field, since around 90 % of articles on the subject have been published after 2010 [15]. Remarkably, this research effort is performed both within academia and industry: according to Li et al. [15], from the current corpus of research efforts in technical debt, 43 % is performed in academia, 40 % in industry and 17 % in both. Apart from the fact that TD is a problem of paramount importance for software

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development, another possible explanation for its prominence in both academia and industry, is its interdisciplinary nature (software engineering and economics), which facilitates the communication among technical and non-technical stakeholders [3]. To achieve this, the TD community *borrows* terms from economics and maps them to software engineering ones.

Based on two recent literature reviews on the subject [3, 15], the two most frequently used financial terms in TD research are: *interest* and *principal*. Principal is a well-defined and accepted concept, which is characterized as the effort required to address the difference between the current and the optimal level of design-time quality, in an immature software artefact or the complete software system [3]. Therefore, it is quantifiable as long as one agrees on the concerned properties (i.e., specific qualities). On the other hand, interest (associated with many definitions, which in some cases are controversial) cannot be measured in a straightforward way, since it involves the valuation of future maintenance activities. Measuring interest becomes even more complicated since its occurrence is not certain, in the sense that maintenance activities might not take place, and therefore interest will not need to be paid off. To partially alleviate these problems, in this study we conduct a systematic literature review which results in a Framework for managing Interest in Technical Debt (FITTED). The goals of FITTED are:

- **(G1)** *to identify types of TD interest, and the parameters that affect its valuation.* Identifying the types of interest, which can occur along evolution, is the first step towards more formal Technical Debt Management (TDM). Until now, the definitions of interest are rather high-level, and interest measurement is often not applied in practice.
- **(G2)** *to explore how various characteristics of interest in economics apply in TD interest.* An example of such a characteristic is whether interest is simple or compound. However, these characteristics have not been fully exploited in research state-of-the-art, yet. Therefore, in this study we first discuss the different opinions stated in the literature, and take them into account when presenting our proposal.
- **(G3)** *to propose a TD interest theory*. Until now, no study has used the economic interest theories for modelling technical debt interest. We will rely on the Liquidity Preference Theory, for modelling the evolution of TD.

The application of FITTED is expected to support software engineers to determine the change of technical debt amount in the future, by describing the parameters that affect its future value (i.e., anticipated maintenance effort, interest, etc.). This can in turn allow the use of elaborate financial methods in different TDM activities, i.e., repayment, monitoring, and prioritization. Additionally, we expect that FITTED can support further research in the field of TD, in the sense that it can facilitate a common understanding on TD interest and point to interesting research directions.

The rest of the paper is organized as follows: In Sect. 2, we discuss related work, i.e., the secondary studies from which we gathered our data (see Sect. 2.1), and background information on interest theory from economics (see Sect. 2.2). Next, in

Sect. 3, we present the research method used in this study. In Sect. 4, we introduce the proposed framework for managing interest in TD. In Sect. 5, we discuss possible paths for further research in the field of TD by employing the proposed framework, whereas in Sect. 6 an illustrative example of its application. Finally, in Sects. 7 and 8, threats to validity and conclusions are presented.

2 Related Work

In this section we present research efforts that are related to this study, and on which the development of the proposed framework is built upon. In particular, we discuss:

- *The corpus of existing research on Technical Debt*, by examining existing systematic literature reviews [14] (see Sect. 2.1). These will provide the primary studies that are reused in the reported systematic literature review.
- *The existing economic interest theories* (see Sect. 2.2). We intend to apply an existing economic interest theory, i.e., *Liquidity Preference Theory*, to reuse existing knowledge from economics, on how interest should be handled, and learn from accumulated experiences.

2.1 Literature Reviews in Technical Debt

Several systematic literature reviews on technical debt have been published during the last three years; a fact suggesting that the issue of technical debt management has become of great interest to both practitioners and academics. Firstly, Tom et al. [26] have published a study in which they explore the nature of technical debt and its implications for software development. In order to achieve this goal they have conducted a multi-vocal literature review and a set of semi-structured interviews among industry practitioners. This research aims at providing indications on how the concept of TD is exploited by both researchers and practitioners. However, the use of non-peer-reviewed reports or articles raises significant reliability and validity issues [21].

In 2015, two secondary studies have been published. Li et al. [15] have performed a mapping study on technical debt and its management (TDM). In this study, the authors present research efforts concerning the concept of technical debt, any related notions and TD management. As a result of the research, TD has been classified into 10 different types, whereas 8 TDM activities have been identified. In addition, Ampatzoglou et al. [3] have conducted a systematic literature review in order to analyze the state of the art on technical debt, by focusing on its financial aspect. Particularly, the analysis is carried out in terms of the definition of financial aspects of TD, and their relation to the underlying software engineering concepts. Finally, even more recently (2016), Alves et al. [2] published the outcomes of a mapping study that aimed to characterize the types of technical debt, identify indicators that can be used to find technical debt, identify management strategies, understand the maturity level of each proposal, and identify what visualization techniques have been proposed to support TD identification and management activities.

Each one of these secondary studies attempts to chart the whole area of TD, while none of them focuses particularly on the topic of interest; this is the aim of our study. In addition to that, since the body of work on TD has already been well scrutinized by the four aforementioned secondary studies, we can build on top of them by reusing the identified primary studies and focusing on interest (see stated goals in Sect. 1).

2.2 Interest in Economics

Regarding the way interest rate is defined in the market; various models have been suggested, by different schools of economics [18]. The mainstream theories are the *Loanable Funds Theory*, developed by the neoclassical school, and the *Liquidity Preference Theory*, proposed by the Keynesian theory [18]. Interest rate is the price paid for borrowing money or vice versa (the payment received to loan money). Therefore it can be considered as the price of money. Interest rate, as any other price, can be defined in the market at the equilibrium between supply and demand. According to the Loanable Funds Theory, interest rate specification takes place in the market of loanable funds. On the one hand, individuals or enterprises, who want to invest, form the demand for loanable funds. They ask for loans in order to proceed with an investment. As interest rate gets higher, borrowing becomes more expensive. As a result, demand for loanable funds decreases as interest rate increases. On the other hand, the supply of loanable funds comes from people or enterprises that use the loanable funds market to save their money. Instead of consuming part of their income, they choose to put it into the loanable funds market in order to save it for later. In this case, higher interest rate means higher return on savings. Therefore, supply of loanable funds rises as interest rate increases.

In the diagram of Fig. 1, the equilibrium in loanable funds market is presented. We note that, in economic theory, all kinds of supply – demand diagrams represent the dependent variable on the horizontal axis and the independent variable on the vertical axis. Therefore, in this case, the vertical axis depicts interest rate (r), while the horizontal axis represents the quantities of supply and demand for loanable funds. The quantity of loanable funds supplied at any level of interest rate is presented by line S. Line S depicts the positive correlation between interest rate and loanable funds supply. Likewise, the quantity of loanable funds demanded at any level of interest rate is presented by line I. The negative correlation between interest rate and loanable funds demand is indicated by the negative slope of line I. When interest rate is higher than r^*, then it is more profitable to save, or it is more profitable to lend than to borrow, and supply of loanable funds is higher than demand. On the other hand, when interest rate r is lower than the level of r^*, then it is more profitable to invest, or it is more profitable to borrow than to lend, and demand for loanable funds is higher than supply. When $r = r^*$, then both the investors and the savers have no motivation to change their position in the market and equilibrium is achieved. Consequently, interest rate is determined at r = r*. Equilibrium in the market is achieved at interest rate r^*, when every other factor, that could influence savings or investment, is considered stable

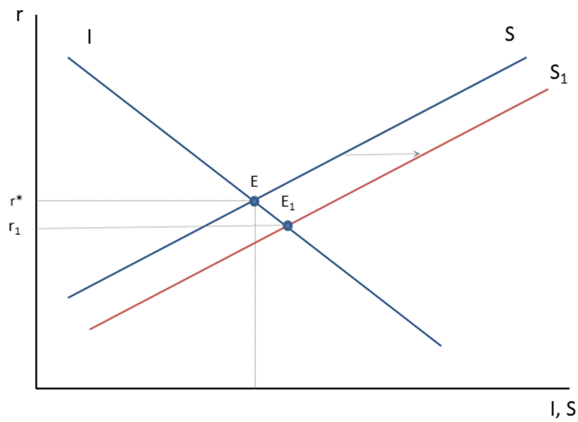

Fig. 1. Loanable funds theory

(ceteris paribus[1]). However, interest rate level may move upwards or downwards in case of changes to savings or investments, due to exogenous factors (e.g., income). For example, an increase in income would cause an increase in the quantity of savings. That would result in a shift to the right of the savings curve (*S*), which is the supply of loanable funds. In Fig. 1, the new line S_1 depicts such a change. As shown in the diagram, the new equilibrium is now achieved at point E_1 and interest rate is defined at r_1, lower than r^*.

The Liquidity Preference Theory determines interest rate level through the mechanism of supply and demand for money (cash), which is performed in the money market. In this case, supply of money (*M*) is a constant at any point of time and is determined by the central bank, according to the needs of the economy. In other words, supply of money is not dependent on interest rate and it is exogenously defined. On the other side, demand for money (*L*) represents the quantity of cash that people prefer to hold for purposes of transactions, precaution or speculation. In this case, as interest rate increases, it becomes more profitable for people to invest money than to hold it. Consequently, an increase in interest rate leads to a decrease in the quantity of money demanded in the market and a decrease in interest rate causes an increase in demand for money. Similarly to the Loanable Funds theory, interest rate is determined by the equilibrium point of the market.

The diagram of Fig. 2 shows the equilibrium in the market of money. Interest rate is represented on the vertical axis, whereas money supply and demand are shown on the horizontal axis. The supply curve is vertical to the horizontal axis, and represents the stable money supply, provided by the central bank, independently of the interest rate level, as mentioned above (this assumption consists the main difference with the loanable funds theory). Demand for money is negatively related to interest rate (because in this case interest rate is the cost of holding money against investing in a bond)

[1] A Latin phrase often used in economics to suggest that all other factors are constant, in order to examine the relationship between two variables.

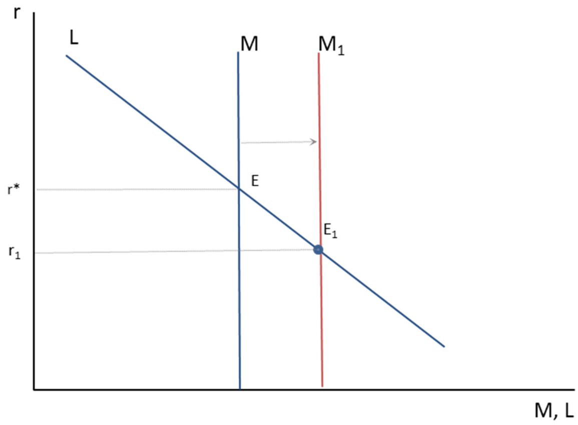

Fig. 2. Liquidity preference theory

and line *L* shows the quantity of money demanded at any given interest rate, ceteris paribus. The intersection of the two curves, *M* and *L*, represents market equilibrium and determines the level of the interest rate at r^*. When interest rate is higher than r^*, then it becomes more profitable for people to invest than to hold their money, so demand for money (cash) is lower than the quantity of money that circulates in the market (excess supply). On the other hand, when interest rate *r* is lower than the level of r^*, then the opportunity cost of money is lower, and people demand for more money than the central bank currently supplies (excess demand). When $r = r^*$, then people want to hold exactly the amount of money they currently have and equilibrium is achieved. In case of a change in demand for money because of a change in another determining factor, e.g. income, or in case of a change in the quantity of money supplied by the central bank, the equilibrium rate will change. For example, if the central bank decides to increase money supply, then *M* would increase to M_1 and the curve in the diagram of Fig. 2 would shift to the right. Consequently, equilibrium would be defined by point E_1 and the new interest rate in the market would be r_1, lower than r^*.

3 Research Method

This work is a systematic literature review that synthesizes knowledge from existing primary studies. The systematic literature review has been designed and executed according to the guidelines presented by Kitchenham et al. [14]. Due to lack of space we do not report the design of the full SLR. The goal of this study is to develop the Framework for managing Interest in Technical Debt (FITTED). Based on the framework's goals (see Sect. 1), we set three research questions[2]:

[2] The mapping between research questions and goals is one-to-one. Therefore, RQ_1 has been set to achieve G1.

[RQ_1] *What are the types of TD interest and the parameters of its valuation?*
[RQ_2] *How characteristics of interest in economics are applied in TD interest?*
[RQ_3] *Can we define a TD interest theory?*

In order to select the studies to be explored in this research effort, we consider the primary studies investigated by Ampatzoglou et al. [3] and Li et al. [15] (see Sect. 2.1). Both these secondary studies are recent and have explicitly investigated the concept of interest, so they can provide a valid and up-to-date set of primary studies. We considered the union of the two sets of primary studies and select those that are related to interest. On the completion of this process, we ended up with *36 studies that focus on TD interest*. In Table 1, we present the reference numbers of the selected studies (as provided by the original secondary studies). In the last column, the total number of primary studies retrieved from every literature review is provided. In the parenthesis, we note the number of studies reported by only one of the two literature reviews, also indicated by the boldface reference numbers. Note that the two secondary studies have obtained different sets of primary studies since they applied different inclusion criteria (e.g., Ampatzoglou et al. [3] excluded all studies that were not using any material from finance).

Table 1. Studies included in this review

Source of reuse	Reference in the original secondary study	Study Count
Ampatzoglou et al. [3]	P1, P2, P7, P8, P9, P10, P12, P13, P15, P16, P17, P22, P23, P24, P26, P30, P35, P37, P38, P41, P42, P51, P52, P53, P57, **P58**, P67, P68, P69	29 (1)
Li et al. [15]	S1, S2, S9, S10, S11, S12, **S15**, S16, S17, S20, S22, S23, S24, S34, S35, S39, **S40**, **S42**, S50, **S53**, S55, S56, S61, S62, S65, S71, S72, S73, **S75**, **S77**, S78, **S85**, S91, S93, S94	35 (7)

The study selection process of the two secondary studies surveying primary studies on TD can be summarized as follows:

Ampatzoglou et al.

- Queried 7 digital libraries (IEEE, ACM, Scopus, Springer, Science Direct, Web of Science, and Google Scholar), with the term *technical debt*. The search returned 1,173 primary studies
- Applied Inclusion/Exclusion Criteria (e.g., the study should focus on the financial aspect of TD). The process returned 69 primary studies.

Li et al.

- Queried 6 digital libraries (IEEEXplore, ACM, Science Direct, Web of Science, Springer Link, Scopus, Inspec, with the term *debt*, in the area of computer science or software engineering. The search returned 1,665 studies
- Applied Inclusion/Exclusion Criteria (e.g., paper should focus on some specific types of TD). The process returned 94 primary studies.

To answer the RQs and construct FITTED (see Sect. 4), we extracted data from the primary studies and combined this information with theory from Economics (see Sect. 2.2). In particular, in order to answer RQ_1, we have isolated all definitions of interest, and the parameters used for its valuation. To answer RQ_2, we have extracted and analyzed all statements regarding how interest evolves over time. To answer RQ_3, we have looked into the accumulation and repayment of interest, as well as the Liquidity Preference Theory. Eventually we performed a synthesis of the data in the primary studies and the aforementioned economics theory. Therefore, to some extent, FITTED represents our own ideas that aim at covering gaps in literature.

4 Framework for Managing Interest in TD

In the next sections we present FITTED, i.e., the proposed framework for managing interest in technical debt, structured based on the set RQs.

4.1 Types of Interest and Parameters of Its Valuation

According to Ampatzoglou et al. [3] and Li et al. [15], interest is the most prominent financial term that is used in TDM research. Note that in economics, interest theories are used for calculating interest rate (not interest per se), since interest is calculated based on interest rate. However, in TDM, interest is not calculated based on interest rate, but it is assessed in various other ways, as explained later in this section. Specifically, from TD research, it is not clear if interest rate can be defined at all. Based on the selected primary studies, technical debt interest is perceived as a risk for software development, in the sense that it has a specific effect (i.e., *interest amount*) and a probability to occur (i.e., *interest probability*). Concerning these two terms:

- 28 % of primary studies describe **interest amount** as the extra effort during maintenance, whereas 50 % as the extra maintenance cost. However, since in software economics, cost is usually defined as a function of effort, we can safely assume that 78 % of studies refer to interest amount as the extra effort/cost that is required during maintenance activities, due to the presence of technical debt. The rest of the studies, either provide more high-level definitions—e.g., [9, 16] —or define technical debt interest similarly to economics, i.e., the increase rate of technical debt amount [10], or define interest as a change in a design-time quality attribute—see for example [23, 28].
- 25 % of the studies acknowledge the existence of **interest probability**. According to Seaman and Guo [22], interest probability refers to the possibility that interest will occur in one item, i.e., that extra effort will be demanded during future maintenance. It should be noted that Technical Debt Items might not be need to be maintained and thus no interest will be paid. From the studies that deal with interest probability, [11, 25] adopt a financial risk management approach where interest probability is calculated as the standard deviation of past interest rate; [13] suggests that interest probability is time sensitive; the rest, as [12] or [22], adopt a risk

management approach, i.e., they consider interest probability as the probability of the TD incurring event to occur.

In addition to the amount and probability of incurred interest, it is useful to distinguish between two different situations when interest can manifest itself:

- ***Interest while performing maintenance activities—IM***: Performing maintenance tasks is more time/effort consuming in software with accumulated TD, compared to the same software if it had no TD (see for example [1, 20] or [23]). The difference between the two amounts of effort is the amount of the *IM* interest. This type of interest will occur, and will be simultaneously paid, when maintenance tasks are performed (i.e., while undertaking the effort to perform the maintenance task).
- ***Interest while repaying TD—IR***: The effort for repaying technical debt at any time point *t* (i.e., enhancing the quality of a Technical Debt Item - TDI to partially or totally remove TD) is higher than the effort needed for repaying technical debt for this item, at any time point prior to *t*, supposing that the TDI has been extended along software evolution—see for example [17, 19]. Therefore, *IR* is calculated as the difference between the two aforementioned efforts. This type of interest will occur when (and if) the amount of TD is to be paid off. For example, consider a long method bad smell that initially consisted of 500 lines of code. During evolution, the same method grows to 750 lines. Thus, the time needed for refactoring it (TDI repayment) increases over time.

Both of the aforementioned types of interest are in agreement with the most established definitions of interest amount (i.e., extra cost/effort); however they add more details on when these extra costs/efforts can occur. Thus, for each technical debt item, interest (I_{TDI}) should be calculated, based on the following high-level formula:

$$
\begin{aligned}
I_{TDI} &= IR_{TDI} + IM_{TDI} \\
&= PR_{TDI} * ER_{TDI} + PM_{TDI} * EM_{TDI},
\end{aligned}
$$

in which *P* denotes the probability of a repayment (R) or maintenance (M) event to occur, and *E* the effort needed to perform the action. For example, ER_{TDI} corresponds to the effort required for repayment in the technical debt item: TDI. To transform the aforementioned formula from the TDI level to the system-level, we propose the use of the sum aggregation function, since the total TD of a system is the sum of TD of all items with incurred TD. Therefore, interest at system level (*I*) can be calculated, as:

$$
I = \sum_{j=1}^{j=count(TDI)} PR_j * ER_j + PM_j * EM_j
$$

We note that to use the aforementioned formulas, one needs to assign estimates for the *PR*, *PM*, *ER*, and *EM* factors; these can either come from experience or from empirical data. For examples and interesting research directions on this issue, see Sect. 5.

4.2 Mapping of Interest Characteristics in Economics on TD Interest

Based on economics, interest is classified over two dimensions: its method of calculation and its variation over time. For these purposes, interest or interest rate can be:

- ***Simple*** or ***Compound***: Interest is simple when it is calculated only as a function of the principal; whereas it is compound when it is calculated over the principal, plus the incurred interest; and
- ***Fixed*** or ***Floating***: Interest rate is fixed, if it does not change along time; whereas it is floating when it can increase or decrease based on circumstances.

The primary studies we looked into, discuss these characteristics of interest, but only superficially, without empirical evidence on the real-world evolution of interest. As already explained in Sect. 4.1, the concept of interest rate does not apply for technical debt. Therefore, the distinction between floating and fixed interest rates is not applicable. Specifically, 19 % of primary studies deal with the evolution of interest along time and either characterize it as compound, or continuously increasing. As an exception to this, Chin et al. [7], propose that the cost of the organization to hold on TD is stable across time and neither increases nor decreases. Finally, only 14 % of the studies propose a specific way of measuring interest. The estimation is commonly performed by using historical data, documentation, and maintenance models.

From the primary studies, we observe that technical debt interest is perceived as *compound*, in the sense that it is increasing, since the additional effort to repay technical debt and perform maintenance on a technical debt item increases as software grows and design-time quality is compromised (see for example [1, 5]). It is suggested that the level of compromised design-time quality (CQ) (e.g. higher complexity or coupling) can be used to calculate the increase of interest. However, it is rather problematic to decompose the level of compromised design-time quality of the system to the level of the original system at time *t1*, $CQ(t_1)$, i.e., the one that existed in the system when the principal incurred, and the additional level of the system at (t_2), i.e., the one that incurred due to system evolution (system larger in size, more functionality, etc.): $\Delta Q = CQ(t_2) - CQ(t_1)$. Therefore, the calculation of the effort needed to perform any maintenance action in t_2, can only be assessed based on current level of compromised design-time quality of the system $CQ(t_2)$. However, in case that some repayment activity is performed (at t_2), we expect that the level of compromised design-time quality of system after partial repayment $CQ(t_2)$ to decrease (i.e., $CQ(t_2) < CQ(t_1)$), leading to a decreased amount of both types of interest, in future maintenance—i.e., ER and EM. These claims are valid for TDIs, in which no additional technical debt has been incurred between timestamps t_2 and t_1.

4.3 Interest Theory

Based on the above, and by borrowing the rationale of the equilibrium achievement from the existing economic interest theories, we developed an interest theory for managing TD interest. Specifically, we adopt the concept of the *Liquidity Preference Theory*. The reason for selecting the *Liquidity Preference Theory* and not the *Loanable Funds Theory* is that in TD the amount of money that is available to the company for

TDM is stable, i.e., the principal (the amount that has been saved, while incurring TD supposing that principal is not invested to provide extra benefits). The assumption that the available money for TDM is the principal is based on the fact that principal is the maximum amount that can be saved without spending any additional effort.

In the proposed interest theory, we map ***money supply*** to ***principal***, in the sense that principal is the amount of money that is available to the software development company, after incurring TD; and we map the ***money demand*** to the ***accumulated amount of interest***, in the sense that this is the extra amount of money that is demanded by the company when performing future maintenance activities, caused by the TD. In Fig. 3, where we present the FITTED Interest Theory, the ***x-axis*** represents ***time***, whereas the ***y-axis*** represents ***amount of money***. Therefore, the equilibrium point (E_0) denotes the time stamp (t_0), in which the company has spent the complete amount of money from the internal loan (i.e., initial principal – P_0) in extra maintenance activities because of the incurred TD. We note that the specification of the equilibrium point is achieved through an analysis based only on effort, i.e., the effort saved when taking on TD and the extra effort required for any future maintenance activity because of its accumulation. Any other related costs or benefits related to technical debt occurrence (e.g. gains from launching the product earlier) have been excluded from the model for simplicity reasons. Thus, if the expected lifespan of the specific TDI is shorter than t_0 then undertaking technical debt is a beneficial choice, whereas if not, technical debt becomes harmful for the company. The aforementioned discussions, in the case that no repayment actions are performed, are summarized in the blue lines of Fig. 3.

Additionally, in Fig. 3, we consider $\Sigma(IM)$ as *continuously increasing*, since it is a sum of positive numbers and because TD interest is compound (see Sect. 4.2). In case that some repayment occurs at some timestamp (t_r), the line of the accumulated

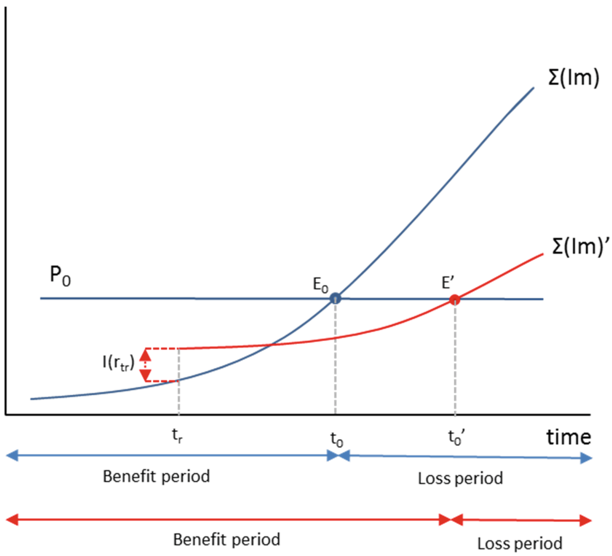

Fig. 3. FITTED interest theory

interest $\Sigma(IM)$ is moved upwards, due to the interest paid for repayment – i.e., $IR(t_r)$ but its slope is decreasing, since the interest is expected to lower for future maintenance activities (IM). This in turn leads to a shift of the equilibrium point (E') to the right, increasing the benefit period (t_0'). The money supply line (P_0) is not moved, because the originally available budget of the company is not affected, assuming zero investment or inflation. The proposed interest theory can help practitioners in their decision making by:

- Identifying the timestamp in which incurring TD, becomes harmful for the company. Thus, they can decide if they should undertake the debt.
- Supporting the continuous monitoring of the interest that has been paid so far.
- Evaluating the repayment activity, based on the time-shift of the equilibrium point that it offers.

5 Research Implications

Research on TD is rather theoretical and lacks empirical evidence. In particular, according to Li et al. 49 % of the complete corpus of TD research presents no empirical evidence, or only toy examples, whereas this number rises to 56 %, when focusing on interest [15]. Thus, in this section we provide future work directions, which could provide empirical evidence on TD interest and support the realization of FITTED.

Types of Interest & Evolution:

- Which one of the two types of interest (IR or IM) produces higher interest amounts when it occurs? Answering this question would suggest which type of interest would be more profitable to manage.
- How can IR and IM amount be modelled, as a function of the principal, or the underlying structure of the TDI? Answering this question would open new research directions in TD management, since more elaborate management approaches could be employed.
- What is the relationship of the decay of quality in the underlying system and the increase in EM or ER? Answering this question could guide practitioners on how to model the increase of interest during software evolution.

So far, these questions have been partially explored by Guo et al. [12], Nugroho et al. [20], and Siebra et al. [24], by exploring historical changes and documentation. The research state-of-the-art lacks real-world evidence on effort allocation.

FITTED Interest Theory:

- What is the expected time (t_0) when the equilibrium will be reached?
- What is the average time-shift from performing specific repayment activities?
- What factors influence this time-shift?
- What is the relationship between IR and the average decrease in the IM of future maintenance activities?

Answering these questions, would enable researchers to instantiate the proposed theory, based on context-specific data, and offer FITTED as a useful tool for practitioners (see Sect. 6).

6 Application of FITTED Interest Theory

As an illustrative example of how the FITTED interest theory can be applied, Chatzigeorgiou et al. [6] proposed an ***empirical setting for calculating the expected time (t_0) when the equilibrium will be reached*** (see first question on FITTED Interest Theory in Sect. 5)[3]. Based on this study, the time point at which the equilibrium is reached has been termed as the *breaking point of technical debt*. To formulate principal and interest, Chatzigeorgiou et al. [6] used the rationale depicted in Fig. 4. In particular, it is assumed that the quality of every system can be calculated with the use of a fitness function. Also, using search-based optimization a design that optimizes the value of this function can be obtained. The effort needed to transform the original system to the optimal one is the ***principal***. Furthermore, it is reasonable to assume that the effort needed to perform any feature addition (EM) on the actual system will be higher than the effort to add the same feature to the optimum system. This difference in effort is ***interest*** (more details can be found in [6]).

To instantiate this approach with a specific implementation, Chatzigeorgiou et al. [6] performed the following actions/assumptions:

- ***Fitness function (FF):*** Ratio between coupling and cohesion, i.e., two well-known software quality characteristics.

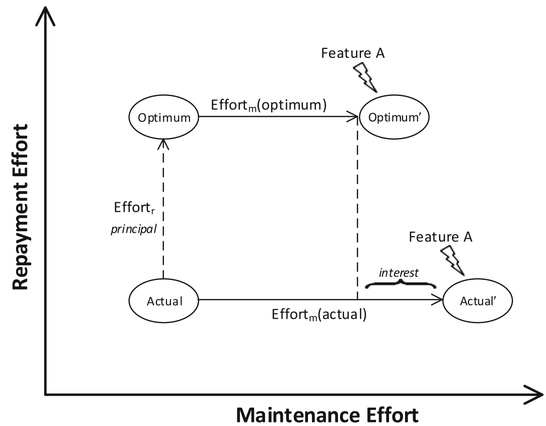

Fig. 4. Increased maintenance effort for technical debt item

[3] We note that for this illustration we have not considered the equilibrium point shift that is described in FITTED, but we only calculate the equilibrium point without any refactoring. (In this illustration we assume that while adding features quality does not further decay.)

- ***Principal***: Number of simple refactorings (move methods, extract class, etc.) needed to transform the actual design to the optimal one. The cost of a simple refactoring according to the literature is 5.73$ [27]
- ***Interest***: The ratio of the levels of design quality (fitness function) is correlated to the ratio of the two `EM` (the actual and the optimum). Thus, and by considering that on average the addition of one line of code costs 1.83$, interest can be calculated as $1.83*LOC_{added}*(1\text{-}FF_{ratio})$.

The application of this approach in an open source system, namely Junit, has shown that an interest of 243$ is accumulated per release and its principal in version 4.10 (starting version) is 1,891$. Therefore, the breaking point will be reached in approximately 8 versions after the start version, i.e., about 5.5 years from the time of analysis (see Fig. 5). We note that for simplicity, Chatzigeorgiou et al., have assumed that interest is a linear function of the FF, therefore, the growth of interest, i.e. Σ(IM), is linear as well, in contrast to Fig. 3.

Consequently, if no TD repayment activities are performed in this time period the difficulty of maintaining this system (interest) will be as high as the effort saved from not having developed the optimal system (principal). However, we need to note that 5.5 years is a long period, and thus, the project is considered to have a sustainable amount of TD.

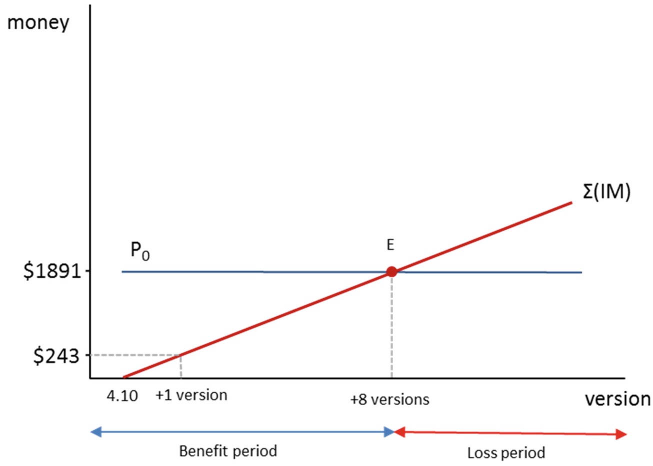

Fig. 5. Application of FITTED interest theory in Junit

7 Threats to Validity

In this study, we report threats to the validity of this research. Since some parts of the research method application are inherited from the secondary studies of Ampatzoglou et al. [3] and Li et al. [15], their threats to validity are also inherited. Therefore, the following threats have been identified:

- ***Possibility of missing primary studies***. We believe that although this threat still exists, we have substantially mitigated it, by considering the union of primary studies reported on the two secondary studies. Also, the fact that their overlap was quite high indicates that their coverage was adequate.
- ***Publication bias***. As both secondary studies report, in many cases research areas in their infancy are biased by the fact that most of the studies are published by a small community. However, we believe that this fact is currently changing in TD, since more and more researchers are getting actively involved in the last years.

Concerning data extraction, since we independently performed this step, the corresponding threats are related only to this study. To mitigate bias while extracting data, two researchers performed data collection independently, compared the results and discussed possible differences. The final dataset was built through the consent of all authors. Finally, as a threat we acknowledge that the construction of the presented formulas, is to some extent based on the understanding of the authors on TD interest.

8 Conclusions

Nowadays, Technical Debt (TD) is receiving increasing interest by both academia and practitioners, leading to an explosion of studies in this field. The cornerstones of TD are two notions borrowed from economics: i.e., *principal* and *interest*. Although principal is a well-established term, interest has so far been discussed in a rather coarse-grained way, with several contradictions among researchers. In this paper, we propose *FITTED*, i.e., a framework for managing interest in TD, which takes into account existing TD literature and economic interest theories. The framework comprises of: (a) the parameters that are used in TD interest valuation, (b) a classification of TD interest types, (c) a characterization of TD interest evolution, and (d) a TD interest theory, based on the Liquidity Preference Theory. The proposed framework is expected to aid in the decision making of practitioners, and points to interesting research directions. The main emphasis of the future research directions is on empirical studies, which until now are underrepresented in the TD research corpus.

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