İstanbul İktisat Dergisi - Istanbul Journal of Economics
70, 2020/1, s. 47-72
ISSN: 2602-4152
E-ISSN: 2602-3954

RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

R&D Intensity, Complementary Assets and Firm Value: Time Series Evidence from Turkey

Ar-Ge Yoğunluğu, Tamamlayıcı Varlıklar ve Firma Değeri: Türkiye için Zaman Serisi Bulguları

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ABSTRACT

This paper aims to test the value relevance of R&D intensity and complementary assets on quarterly time-series data regarding the R&D activities of Turkish manufacturing sector (comprising BIST listed manufacturing firms) in the period of 1992.Q1-2019.Q3. The presence of a unit root is tested by Augmented Dickey Fuller (1981) and Zivot and Andrews (1992) tests. Following this, one-break Gregory and Hansen (1996) cointegration test is employed to detect structural break in the cointegrating relationship among series. Finally, the long-run coefficients estimated by Stock and Watson (1993)'s method of DOLS indicate that R&D intensity variable relative to net sales has statistically significant and positive effect on firm value, which then turns negative following the break date. The other R&D intensity variable relative to total assets fails to reveal any significant effect on firm value, both in the pre- and post-break date. Besides, complementary (tangible) assets have statistically significant and negative effect on firm value until the break date and this effect reverses following the break date. The break date of 2005.Q1 can be associated with the time-lag effects of several severe crises that the Turkish economy has experienced between 1999 and 2001.

Keywords: R&D intensity, Firm value, Complementary assets, Time series analysis, Borsa İstanbul
JEL Classification: C22, D25, O32

ÖZ

Bu çalışmada; 1992.Q1-2019.Q3 dönemini kapsayan zaman serisi verisi kullanılarak Türkiye'de imalat sanayi sektöründe, ar-ge yoğunluğu ile tamamlayıcı varlıkların firma değeri üzerindeki olası etkilerinin araştırılması amaçlanmaktadır. Serilerin durağanlık düzeyleri ADF (1981), ve Zivot ve Andrews (1992) birim kök testleri kullanılarak tespit edilmektedir. Seriler arasındaki uzun

DOI: 10.26650/ISTJECON2020-0017

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Submitted/Başvuru: 11.05.2020
Accepted/Kabul: 18.05.2020

Citation/Atıf: Demirgunes, K. & İltas, Y. (2020). R&D intensity, complementary assets and firm value: time series evidence from Turkey. *İstanbul İktisat Dergisi - Istanbul Journal of Economics, 70*(1), 47-72.
https://doi.org/10.26650/ISTJECON2020-0017

dönemli ilişkiler tek yapısal kırılmaya izin veren Gregory ve Hansen (1996) eşbütünleşme testi ile incelenmektedir. Son olarak, aralarında eşbütünleşme ilişkisi tespit edilen değişkenler arasındaki uzun dönemli ilişkileri gösteren katsayıların tahminlemesinde, yapısal kırılmaların kukla değişken olarak analize dâhil edilebildiği Stock ve Watson (1993) tarafından geliştirilen dinamik en küçük kareler yöntemi kullanılmaktadır. Dinamik en küçük kareler tahmincisi sonuçlarına göre; ar-ge yoğunluğu değişkenlerinden "ar-ge harcamaları/net satışlar" ile tamamlayıcı varlıklara ilişkin değişkenlerin, firma değerine karşı uzun dönem katsayıları istatistiksel olarak anlamlıdır. Kırılma tarihi (2005.Q1) de dahil olmak üzere, bu tarihe kadar, "ar-ge harcamaları/net satışlar" değişkeninin firma değerini pozitif yönde etkilediği görülürken; söz konusu etkileşim kırılma tarihi sonrasında negatife dönmektedir. Tamamlayıcı varlıklara ilişkin değişken ise kırılma tarihine kadar firma değerini negatif yönde etkilerken, söz konusu etkileşim kırılma tarihi sonrasında tersine dönmektedir. Bir diğer ar-ge yoğunluğu değişkeni olan "ar-ge harcamaları/toplam aktifler" değişkeninin ise gerek kırılma tarihinden önce gerekse de sonra firma değeri üzerinde anlamlı bir etkisi bulunmamaktadır.

Anahtar kelimeler: Ar-Ge yoğunluğu, Firma değeri, Tamamlayıcı varlıklar, Zaman serisi analizi, Borsa İstanbul
JEL Sınıflaması: C22, D25, O32

1. Introduction

The market value of a firm's stocks refers to the value of all its net tangible and intangible assets. The efficient market hypothesis assumes that stocks are always traded at their fair value, reflecting all available information about them; so, it is not possible for investors to outperform the market. It is known that these assumptions do not fit the real world. For a tangible asset-intense firm, the relevance between asset values and stock prices is relatively noticeable. However, in especially developed and developing economies, an increasing proportion of firm value derives from intangible assets. Intangible assets, by definition, entitle a firm to generate rights, privileges and other economic benefits for the owner; and are difficult to value as they are not traded in the market. Therefore, fair value of an intangible asset cannot be properly accounted in financial statements (Fung, 2003). Despite the inevitability of uncertainty by their very nature, many economies worldwide have witnessed the growing importance and growth rate of intangible assets surpassing that of tangibles (Corrado et al., 2012; 2016). Referring to the 2019 Intangible Assets Financial Statement Impact Comparison Report, the most striking and remarkable evidence of the shift from tangible- to intangible-based economies can be the figures reflecting the shifting drivers of value in the S&P 500 Index. As recently as 1975, while intangible assets made up a mere 17% of the total market value on the Index, this percentage has risen to 68% by 1995 and 84% by 2018. This value shift is more observable in especially digital-centric sector firms (such as internet, software, information technologies and telecommunications firms) that make substantial investments for research and development (R&D) activities, rather than resource providers or financial intermediaries (Jen and Scott, 2017). In recent years, the dominant firms in stock market capitalization rankings are such sector firms as given in Table 1.

Table 1. Annual Ranking of Firms Based on Intangible Value (2019)

Rank	Firm	Sector	Total Intangible Value (in billion US$)	Share of Firm Value
1	Microsoft	Internet & Software	904	90%
2	Amazon	Internet & Software	839	93%
3	Apple	Technology & IT	675	77%
4	Alphabet	Internet & Software	521	65%
5	Facebook	Internet & Software	409	79%
6	AT&T	Telecommunications	371	84%
7	Tencent	Internet & Software	365	88%
8	Johnson & Johnson	Pharmaceutical	361	101%
9	Visa	Banking	348	100%
10	Alibaba	Internet & Software	344	86%

Note: Percentages may exceed 100% due to rounding;
Source: Brand Finance Global500 Report (January 2019).

Apart from physical or financial assets, intangible assets comprise a very comprehensive set of assets based on immaterial resources that can be categorized as (*i*) marketing related intangible assets (such as trademarks and internet domain names); (*ii*) customer related intangible assets (such as customer lists and customer relationships); (*iii*) artistic related intangible assets (such as literary works and television programs); (*iv*) contract based intangible assets (such as licensing and franchise agreements); and (*v*) technology based intangible assets (such as patented technology and trade secrets). As seen, they are indeed related to every aspect of a business including finance, accounting, marketing, strategic and human resource management, information systems, knowledge management etc. (Marr and Chatzkel, 2004), as key value drivers whose essence is an idea or knowledge (Hall, 1992).

Surprisingly, the literature has focused extensively on one dimension of intangible assets, R&D activity. According to Chan et al. (2001), widespread technological changes together with the enormous progress in science- and knowledge-based industries active in R&D account for this focus of interest. The rise in the importance of R&D also raises a finance related question of whether the intangible R&D investments and/or expenditures are fairly valued by the market. In an efficient market, as the value of R&D investments and/or expenditures is also reflected by the stock price, there is no relationship between R&D and stock returns. On the other hand, long-term financial performance of an R&D intensive firm with fewer tangible assets is highly unpredictable, as it mostly depends on the market success of new and innovative products or technologies. Considering the life cycle of an R&D intensive firm, start-up phase necessitates large investments and/or expenditures. However, the materialization process of outcomes, if any, is mostly uncertain and tends to take a long time to yield significant returns.

Another issue is the accounting information about R&D, as it is generally of limited usefulness. While accounting theory rules that R&D expenditures can be charged to expense as incurred, IAS (International Accounting Standards) 38 prescribes the partial capitalization of R&D expenditures. Whether R&D expenditures should be capitalized or treated as expense is a considerable debate beyond accounting procedures. Uncertainty and difficulty of quantifying future benefits of R&D activities complicate the capitalization of R&D expenditures as an asset; because accounting defines assets as "*probable future economic benefits obtained or controlled by a particular entity as a result of past transactions or events* (FASB Concept Statement 6, paragraph 25)", and the most obvious evidence of future economic benefit is the market price of the asset. Besides, R&D expenditures have direct effects on calculations of firm value and profitability. R&D capitalization will increase firm profitability -at least on paper-, the book value of assets and hence firm value. Such a policy could be rational for small or start-up firms with significant R&D expenditures in securing investors' capital for growth. Lev and Sougiannis (1996), and Aboody and Lev (1998) have provided empirical evidence of R&D capitalization being beneficial in terms of market value explanatory power and information asymmetries. Also, as concluded by Healy et al. (2002), R&D capitalization allows firm managers to discretionarily capitalize the costs of projects with lower probability of success and to delay the write-down of impaired R&D assets.

Though there is vast evidence that stock markets tend to value firms with major R&D investments (Jaffe, 1986; Connolly and Hirschey, 1990; Hall, 1993; Hall, 2000; Oriani and Sobrero, 2003; Shortridge, 2004; Czarnitzki et al., 2006) and

R&D expenditures (Cockburn and Griliches, 1988; Erickson and Jacobson, 1992; Chan et al., 2001; Daniel and Titman, 2006; Heeley and Jacobson, 2008) positively, as these firms take advantages of technological innovations; the link between firm value and, R&D investments and/or expenditures still remains unclear. The reason may be the uncertainties arising from differing perspectives of finance and accounting that misguide investors to underestimate or overestimate the market value of R&D investments. Hall (1993) suggests that short-term investors may be unwilling to anticipate return on long-term R&D investments and underestimate them. These investors, as contrary to long-term investors who prioritize the drivers of long-term returns such as future cash flows and expected returns, mostly try to predict stock price changes focusing on news flow and positions of other short-term investors (Warren, 2014). Hence, this financial myopia can cause significant reductions in their expected future returns. Besides, the distorting effects of R&D may lead investors using only accounting information to erroneous assessments in the process of firm valuation.

On the other hand, other studies observe that the market sometimes tends to value technology firms making large R&D investments and/or expenditures (very) excessively, reflecting market's over-optimism about the effect of R&D on future returns. This excessive valuation of R&D firms is mostly the result of unrealistic optimism which, in psychology, refers to the propensity for individuals to believe that they are less likely to experience negative events, compared to the average person (Aucote and Gold, 2005). Accordingly, in financial economics, optimistic investor is defined as one who overestimates the probability of good outcomes and underestimates the probability of negative outcomes (Kahneman and Lovallo, 1993). These biased estimations lead them to riskier behaviors in their investment decisions. The dot-com bubble of the 1990s in United States can be a great example of stock market bubbles caused by such excessive optimism (and speculation) in internet-related firms. The value of United States stock market capitalization doubled between 1990 and 1995, and then tripled between 1995 and 2000, ending with a sharp downward adjustment that started in March 2000. By 2003, stock market capitalization had fallen by about 25%. Examining analysts' forecasts of returns for internet-related firms, Liu and Song (2001) have reported that their optimistic expectations before and after the March 2000 period might be the main cause of the bubble. One attractive characteristic of R&D firms' stocks is the tendency to have relatively low book-to-market ratios. Fama and French (1992), and Lakonishok et al. (1994) have provided evidence that such stocks generally perform poorly in the future, mainly due to the investors' overestimated (and excessively optimistic) expectations on future returns from technological breakthroughs promised by R&D firms.

This paper, in general, aims to test the value relevance of R&D expenditures and complementary assets on a quarterly time-series data regarding the R&D activities of Turkish manufacturing sector covering the period of 1992.Q1-2019.Q3. Overall, this paper contributes to corporate finance literature in several ways. First, it considers R&D intensity using two different proxies simultaneously in the same empirical research model. Second, it focuses on manufacturing sector categorized by OECD as a medium low-technology or low-technology (LMT) and a forgotten sector in innovation policy[1]. As known, LMT sectors play a very unique role both as a catalyst for productivity growth and income convergence, and as a provider of employment in entire economies. Third, the empirical model is based on the market-to-book ratio, a forward-looking financial performance measure, as a proxy for firm value and the model is tested by advanced econometric methodologies by using quarterly time-series data. The rest of the paper is as follows. The literature review is given in Section 2. Section 3 presents data, variable definitions, the research model, econometric methodologies to be employed and empirical findings. Finally, Section 4 concludes the paper by discussing empirical findings, presenting the limitations and suggestions for further studies.

[1] R&D intensity calculated as the ratio of R&D expenditures to net sales is a common indicator used internationally related to R&D activity of a firm or a business sector, covering in-house R&D expenditures for R&D staff, further R&D costs and investments plus out-house expenditures for, e.g., R&D tasks assigned to other companies and organizations (OECD, 2002, p. 108). OECD categories sectors with R&D intensity more than 5% as high-technology sectors; sectors with R&D intensity between 3% and 5% as medium high-technology and those with R&D intensity below 3% as medium low-technology or low-technology sectors. While, pharmaceuticals, electronic, mechanical engineering, vehicle and aerospace construction, for instance, are referred to as high-technology sectors; more "conventional" sectors such as the manufacture of household appliances, the food, the paper, publishing and print, furniture and the manufacture of metal products are regarded as medium low-technology or low-technology sectors, such as the sample of this paper (Hirsch-Kreinsen, 2008).

2. Literature Review

The proposition that the market value of a firm (as a measure of firm performance) reflects its innovation capacity derives from the notion that R&D investments and/or expenditures tend to create value. This proposed relationship between R&D investments and/or expenditures, and firm value has firstly been subject of several important studies by Ben-Zion (1978), Griliches (1981), Ben-Zion (1984), Connolly and Hirschey (1984), and Jaffe (1986). Though the market value measures (Tobin's q, market value, market-to-book, abnormal returns, etc.) in their models differ from each other, they all empirically found that R&D has significant positive effect on market value of the firm.

Following these pioneering studies, empirical studies has expanded vastly at the beginning of 1990s, mostly assuming a linear relationship between R&D investments and/or expenditures and different firm performance measures (see, for instance, Chan et al. 1990; Doukas and Switzer, 1992; Green et al., 1996; Hall, 2000; Joseph, 2001; Bae and Kim, 2003; Xu et al., 2007; Tubbs, 2008; Chen et al., 2019). In these studies, R&D investments and/or expenditures are measured either in terms of contemporaneous R&D expenditures or R&D capital estimates, providing empirical evidence generally supporting the conclusion that R&D has significant positive effect on firm performance irrespective of what R&D measure is (Callen and Morel, 2005).

One major issue of interest in the literature, -to the best of our knowledge- firstly raised by Chang and Su (2010), is the possible existence of nonlinear relationship between R&D and firm performance. According to them, R&D can significantly improve a firm's performance only by reaching an estimated threshold value, and above that value, it is likely to have insignificant or negative effect on firm performance. This finding is also confirmed by many studies. Bae et al. (2008)'s study on US manufacturing firms, concluded that the relationship between R&D and firm performance is not monotonic and varies due to firm's multinationality phase, as negative at the initial stage, followed by a positive and then again a negative relationship. Moreover, studies by Pantagakis et al. (2012)

on 39 European firms, Choi and Williams (2014) on Chinese firms, Naik (2014) on Indian manufacturing firms, and Xu and Jin (2016) on China's Internet of Things industry all provide empirical evidence on the nonlinear relationship between R&D and financial performance. Recently, Kim et al. (2018) suggest that due to increase in R&D investment, firm value increases to a threshold value and then begins to decrease, while Chen and Ibhagui (2019) find that firms with higher R&D intensity do not necessarily outperform those with low R&D intensity.

Though outnumbered, there is evidence that there is no or negative relationship between R&D and firm performance. While Lin et al. (2006) point that there is no significant relationship between R&D (as proxied by patents) and firm performance; Hartmann et al. (2006) and Wang et al. (2011) provide evidence on the negative relationship between the variables. This negative relation can be attributed to the high riskiness of R&D activities. It is well known that the level of risks in R&D activities is relatively high compared to production and service development projects, and these activities are likely to affect firm profitability more critically than routines. Besides, uncertainty in market demand and very rapidly changing technology can cause unpredictable variations in R&D profitability of high-technology firms. In the early 1990s, IBM was the paragon of such a high-technology firm facing a near failure (with a loss of approximately $16 billion and a declining market share to 26% compared to 70% in the 1960s and 1970s), though it had spent billions of dollars annually on R&D activities.

3. Empirical Design

This paper empirically analyzes the relationship between R&D intensity and firm value. First, the presence of a unit root is tested by Augmented Dickey Fuller (ADF, 1981) and, Zivot and Andrews (ZA, 1992) tests. Following this, one-break Gregory and Hansen (1996) cointegration test is employed to detect structural breaks in the cointegrating relationship among series. In the final step of the analysis, Stock and Watson (1993)'s method of dynamic ordinary least squares (DOLS) is performed to estimate the long-run cointegration coefficients that explain the relationships among the series.

3.1. Data and Variables

This paper conducts an empirical analysis on Turkish manufacturing sector with all 18 main- and 30 sub-sectors using a time series data set covering 1992.Q1-2019.Q3. The data set consists of quarterly data of all Borsa Istanbul (BIST) listed manufacturing firms operating in these main- and/or sub-sectors and is derived from FINNET Financial Analysis Program.

The dependent variable of the research model is firm value proxied by market-to-book ratio. In financial valuation and management literature, this ratio is widely used in empirical models either to indicate the value attributed to a firm's stocks or net assets by its investors (Lee and Makhija, 2009), or to measure the operating efficiency. On the other hand, Daniel and Titman (1997), Griffin and Lemmon (2002) and Ali et al. (2003) link the reverse of market-to-book ratio (i.e. book-to-market ratio) to financial risk due to reversal effect which means that future returns on a stock can be predicted for profit. Market-to-book ratio conveys information about the current and future prospects of the firm also including intangible investments (and expenditures) on R&D and intellectual property. As the market tends to view R&D and intellectual property related expenditures of a firm as sort of its long-term investment, these expenditures should be reflected in firm's market-to-book ratio.

The main explanatory variables in the research model are two different R&D intensity measures. These are the ratio of total R&D expenditures to net sales as used in related studies of Wang and Thornhill (2010), Katila and Ahuja (2002), Zhang and Mohnen (2013), and Alessandri and Pattit (2014); and the ratio of total R&D expenditures to total assets proposed by Berrone et al. (2007) and, Grabinska and Grabinski (2017). Though the first measure is used more frequently in the literature, this combination is more appropriate, because R&D investments and/or expenditures can be expressed relative to either net sales (as R&D intensity), book value of total assets or equity, market value of equity, net income, or total dividends. According to Asthana and Zhang (2006), R&D intensity has two effects on firm related to competition mitigation and risk. The competition mitigation effect distinguishes the firm from its competitors and prevents new market entrants. The risk effect is due to the very nature of R&D investments and/or expenditures, as these are mostly discretionary investments and expenditures under high uncertainty and may well lack the production of any tangible asset. These measures are also superior to any other R&D measures considering the absolute R&D investment amount, because they both allow R&D investments and/or expenditures levels of firms with a variety of different sizes in the same market to be distinguished as similar to the sample of this study (Ehie and Olibe, 2010).

Another debate related to R&D activity is on whether it should be capitalized or expensed. According to Healy et al. (2002), while capitalization (implicitly) links R&D activity with firm value, expensing is relatively objective and reliable due to its nature as an accounting term. Some proponents of R&D capitalization (Healy et al., 2002; Kothari et al., 2002; Ahmed and Falk, 2006; Daniel and Titman, 2006; Duqi et al., 2011; Wang and Fan, 2014) argue that R&D capitalization is an important indicator for the performance of investment projects of high R&D intensity firms, which serves as a mechanism for signaling their current and future prospects to the market. However, it is possible that the market may sometimes fail to anticipate any future benefit from R&D activity (see, Hall, 1993). Moreover, defenders of R&D expensing argue that it does not allow the capitalization of costs of projects with low probability of success or for intentional delay in writing down impaired R&D assets (Wang et al., 2017).

In addition to R&D intensity, related studies have vastly focused on effects of other traditional factors such as capital structure, firm size, firm growth, market share etc. as control variables on firm performance. This paper differs from those by also considering the effect of complementary, i.e. tangible assets on firm value. Some authors, such as Lev and Sougiannis (1996), Eberhart et al. (2004), Ehie and Olibe (2010) and Li (2011) implicitly assume independency between R&D activity and tangible assets. However, studies of Teece (1986), Afuaf (2001), Lin et al. (2009), Bena and Li (2014) gather evidence that firms with assets and/or capabilities complementary to R&D perform better than those lacking of such assets and benefit better from R&D. Therefore, to investigate the possible effect of complementary assets on firm performance, (the natural logarithm of) tangible assets is included in the research model as a control variable. Table 2 depicts definitions for each variable in the research model.

Table 2. Variable Definitions

Variable Type	Variable Name	Variable Abbreviation	Variable Calculation
Dependent variable	Market-to-book ratio	*MB*	The ratio of the market value of the stock to the book value per share
Independent variables	R&D intensity$_{(a)}$	$RD_{(a)}$	The ratio of total R&D expenditures to net sales
	R&D intensity$_{(b)}$	$RD_{(b)}$	The ratio of total R&D expenditures to total assets
Control variable	Complementary assets	*COMP*	Natural logarithm of tangible assets

3.2. Research Model

In the research model, *MB* is described as a function of $RD_{(a)}$, $RD_{(b)}$ and *COMP* as given in Equation 1:

$$MB_{it} = \alpha_{0i} + \beta_{1i}RD_{(a)it} + \beta_{2i}RD_{(b)it} + \beta_{3i}COMP_{it} + \varepsilon_{it} \quad (1)$$

where, α_i is constant, $\beta_{i1\text{-}3}$ are coefficients of variables l thru 3 and ε_i is residual term.

3.3. Empirical Findings

3.3.1. Unit Root Test Results

The unit root test procedure is employed to determine whether a financial variable follows a random walk or not. In case of that the presence of a unit root for a series cannot be rejected, the series can be said to follow a random walk. Among the several unit root tests, this study employs ADF (1981) and ZA (1992) unit root tests for detecting the presence of a unit root.

ADF (1981) test is an extension of Dickey-Fuller (DF, 1979) test which is based on the model of the first-order autoregressive process as given in Equation 2 (Box and Jenkins, 1970):

$$y_t = \phi_1 y_{t-1} + \varepsilon_t, \qquad t = 1, \dots, T \quad (2)$$

where ϕ_1 is the autoregression parameter and ε_t is the non-systematic component of the model that meets the characteristics of the white noise process.

The null hypothesis as $H_0{:}\phi_1 = 1$ means that the process contains a unit root and is nonstationary [*I*(1)], and the alternative hypothesis as $H_1{:}\ |\phi_1| < 1$ means that the process does not contain a unit root [*I*(0)].

Equation (2) can be expanded by a constant or a linear trend as given in Equations 3 and 4:

$$y_t = \beta_0 + \phi_1 y_{t-1} + \varepsilon_t \quad (3)$$

$$y_t = \beta_0 + \beta_1 t + \phi_1 y_{t-1} + \varepsilon_t \quad (4)$$

ADF (1981) test is conducted in the case when a non-systematic component in DF (1979) models is autocorrelated. Equation (2) is then transformed into Equation 5:

$$y_t = \phi_1 y_{t-1} + \sum_{i=1}^{p-1} y_i \Delta y_{t-1} + \varepsilon_t \quad (5)$$

ADF (1981) test statistic is calculated as given in Equation 6:

$$\Delta y_t = (\phi_1 - 1) y_{t-1} + \sum_{i=1}^{p-1} y_i \Delta y_{t-1} + \varepsilon_t \quad (6)$$

The common deficiency of this conventional unit root test is the choice of lags *p*. The maximum lag is $p_{max} = 12(\frac{T}{100})^{1/4}$; but, when *p* is too low, autocorrelation will affect the test and when *p* is too large, the explanatory power will be relatively low (Arltova and Fedorova, 2016). The limiting distribution of test statistics is identical with the distribution of DF test statistics and for $T \to \infty$ is tabulated in Dickey (1976) and MacKinnon (1991).

Major events, such as economic crises, catastrophes and pandemics, may affect the series subject to the analyses, because they may create a tendency towards structural break or breaks in the series. Unfortunately, the conventional unit root tests, such as the ADF (1981), Kwiatkowski-Phillips-Schmidt-Shin (KPSS, 1992) and Phillips ve Perron (PP, 1988) tests, do not allow for any possibility of a structural break or breaks, leading to biased results. Such cases require referring advanced unit root tests that allow for the presence of structural break or breaks. Therefore, this study also employs ZA (1992) unit root test with endogenous structural break.

As a variation of Perron (1989)'s original test, ZA (1992) unit root test assumes that the exact timing of the structural break point is not known. The data dependent algorithm they developed to determine the break point is indeed a proxy for Perron (1989)'s subjective procedure. The main difference between the models of Perron (1989) and ZA (1992) is that while the first is a predetermined break, the latter is an estimated break.

ZA (1992) suggest three models to test for a unit root: (*i*) model A with a one-time change in the level of the series; (*ii*) model B with a one-time change in the slope of the trend function, and (*iii*) model C combining one-time changes in the level and the slope of the trend function of the series. The regression equations of these three models are as given in Equations 7, 8 and 9:

$$\Delta y_t = c + \alpha y_{t-1} + \beta t + \gamma DU_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t \ (model\ A) \quad (7)$$

$$\Delta y_t = c + \alpha y_{t-1} + \beta t + \theta DT_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t \ (model\ B) \quad (8)$$

$$\Delta y_t = c + \alpha y_{t-1} + \beta t + \theta DU_t + \gamma DT_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t \ (model\ C) \quad (9)$$

where DU_t is an indicator dummy variable for a mean shift occurring at each possible break date (*TB*), while DT_t is variable for corresponding trend shift. Formally,

$DU_t = \{1 \ldots if\ t > TB\ \ 0 \ldots otherwise$ and $DT_t = \{\ t - TB \ldots if\ t > TB\ 0 \ldots \ldots . otherwise$

The null hypothesis for all models is $\alpha=0$, implying that the series (y_t) contains a unit root with a drift that excludes any structural break, while the alternative hypothesis $\alpha<0$ is that the series is a trend-stationary process with a one-time break occurring at an unknown point of time.

ADF (1981) and ZA (1992) unit root test results indicating that series are stationary at their first differences and integrated of order one, [*I*(1)] are presented in Table 3.

Table 3. ADF (1981) and ZA (1992) Unit Root Test Results

Variable Name		Level		First Differences	
		ADF	ZA[c]	ADF	ZA[c]
MB		-2.087	-4.60 [2008.Q4]	-9.734***	-5.90*** [2001.Q4]
$RD_{(a)}$		-2.308	-4.41 [2008.Q1]	-14.158***	-5.61*** [2008.Q1]
$RD_{(b)}$		-2.054	-4.34 [2008.Q2]	-5.737***	-6.36*** [2008.Q4]
COMP		-2.024	-3.81 [2003.Q4]	-9.332***	-7.34*** [2007.Q4]
Critical Values	1%	-3.497	-5.57	-3.497	-5.57
	5%	-2.890	-5.08	-2.890	-5.08
	10%	-2.582	-4.82	-2.582	-4.82

Note: *** implies significance at the 1% level and denotes rejection of the H_0. Critical values are obtained from ADF (1981) and ZA (1992). Break dates are given in brackets.

3.3.2. Cointegration Test Results

In this study, one-break Gregory and Hansen (1996) cointegration test is employed to detect structural break in the cointegrating relationship among series. This test tests the null hypothesis of no cointegration against an alternative of cointegration with a single structural break in an unknown date based on extensions of the traditional *ADF*, $Z_\propto$ and Z_t-test types.

Gregory and Hansen (1996) suggest three models of (*i*) level shift (C), (*ii*) level shift with trend (C/T) and (*iii*) intercept with slope shifts (C/S) to test for cointegration with structural breaks as adopted to model of the study as given in Equations 10, 11 and 12, respectively:

$$y_t = \mu_1 + \mu_2\varphi_t + \alpha_1 a_t + \alpha_2 b_t + \alpha_3 c_t + \varepsilon_t \ (C\ model) \quad (10)$$

where a_t, b_t and c_t and the dependent variable y_t are [I(1)], the error term ε_t is and [I(0)] the parameters are μ, α_1, α_2 and α_3 time invariant; and μ_1 and μ_2 represent the intercept before and after the shift, respectively.

$$y_t = \mu_1 + \mu_2\varphi_t + \beta_t + \alpha_1 a_t + \alpha_2 b_t + \alpha_3 c_t + \varepsilon_t \left(\frac{C}{T} model\right) \quad (11)$$

where β is the coefficient of the trend term, t.

$$y_t = \mu_1 + \mu_2\varphi_t + \alpha_1 a_t + \alpha_{11}\varphi_t a_t + \alpha_2 a_t + \alpha_{22}\varphi_t a_t + \alpha_3 a_t + \alpha_{33}\varphi_t a_t + \varepsilon_t \left(\frac{C}{S} model\right)$$

where α_1, α_2, α_3 and α_4 denote the cointegrating slope coefficients before the regime shift and α_{11}, α_{22} and α_{33} denote the change in slope coefficients.

Due to that the timing of the regime shift is known a priori, it is possible to use the same approaches for testing all the models given in Equations 10, 11 and 12. However, it is not possible to know the exact timings of regime shifts. Gregory and Hansen (1996)'s test is proposed for testing the cointegration in situations with an unknown break date. Therefore, it requires computing the common statistics (ADF and Phillips test statistics) for all possible break points (τ) and then selecting the smallest values to determine the most appropriate break dates. This procedure of selecting small values of test statistics potentially constitutes evidence against the null hypothesis of no cointegration.

Formulations of ADF (*ADF**) and Phillips test statistics (Z^*_t and $Z^*_\propto$) are as given in Equations 13, 14 and 15 (Gregory and Hansen, 1996: 106):

$$ADF^* = ADF(\tau) \quad (13)$$

$$Z_t^* = Z_t(\tau) \quad (14)$$

$$Z_\alpha^* = Z_\alpha(\tau) \quad (15)$$

The critical values calculated are obtained from Table 1 in Gregory and Hansen (1996). If calculated test statistics are greater than the critical values, there exists a cointegration relationship among the series, rejecting the null hypothesis of no cointegration. Cointegration test results are given in Table 4.

Table 4. Cointegration Test Results of Gregory and Hansen (1996)

Model	Break Date	Test Statistics		
		ADF*	Z^*_t	Z^*_α
C/S	2005.Q1	-6.01**	-5.94**	-77.77**

Note: ** implies significance at the 5% level. For C/S Model, critical values for *ADF** and Z^*_t are -6.51, -6.00 and -5.75 at the 1%, 5% and 10% significance levels; while critical values for Z^*_α are -80.15, -68.94 and -63.42 at the 1%, 5% and 10% significance levels, respectively [obtained from Gregory and Hansen (1996: 109)].

3.3.3. Estimation of Long-Run Coefficients

This study employs Stock and Watson (1993)'s method of DOLS which is improved on ordinary least squares (OLS) and is used to estimate the long-run cointegration coefficients. DOLS method has certain advantages over both OLS and the maximum likelihood procedures, because it deals with small sample and dynamic sources of bias. As a robust single equation approach, DOLS corrects for regressor endogeneity by the inclusion of leads and lags of the first differences of the regressors, and for serially correlated errors by a generalized least squares procedure (Esteve and Requena, 2006, p. 118). Moreover, it has the same asymptotic optimality properties as the Johansen (1991) distribution. In order to use DOLS estimators, existence of cointegration relationship between dependent and explanatory series is required. The DOLS estimator is obtained as given in Equation 16:

$$y_t = \alpha_0 + \alpha_1 t + \alpha_2 x_t + \sum_{i=-q}^{q} \delta_i \Delta x_{t-i} + \varepsilon_t$$

where q and ε_t represent optimum leads and lags, and the error term, respectively.

The estimated long-run coefficients given in Table 5 indicate that considering the break date, R&D intensity variables have mixed effects on firm value. Until the second quarter of the year 2005, R&D intensity variable using net sales as the denominator, $RD_{(a)}$, had a statistically significant and positive effect on firm value, which then turned negative following the break date. Before and after the break date, the coefficients of $RD_{(a)}$ are 553.529 and -35.726 (553.529-589.255), respectively. The other R&D intensity variable in the model using total assets as the denominator, $RD_{(a)}$, fails to reveal any significant effect on firm value, both in the pre- and post-break date. The control variable included in the model as a proxy for complementary assets, *COMP*, has opposite effects on firm value, compared to $RD_{(a)}$. COMP has statistically significant and negative effect on firm value till the break date and this effect reverses following the break date. Before and following the break date, the coefficients of *COMP* are -0.286 and 0.593 (-0.286+0.879), respectively. The break date of 2005.Q1 can be associated to the time-lag effect of R&D activity as a result of several severe crises that the Turkish economy has experienced between 1999 and 2001 (for the impact of R&D activity on firm value through the time-lag effect, see Bhagat and Welch, 1995; Connolly and Hirschey, 2005; Park et al., 2010; Lee and Choi, 2015).

Table 5. Long-Run Coefficients Estimated by DOLS

Variable	**Coefficient**	**Standard Error**	***t*-statistic**
Intercept	5.463***	1.035	5.277
RD(a)	553.529***	172.378	3.211
RD(b)	-67.714	195.392	-0.347
COMP	-0.286***	0.082	-3.476
D	-15.061***	3.758	-4.007
D RD(a)*	-589.255***	191.329	-2.714
D RD(b)*	14.293	213.794	0.066
*D*COMP*	0.879***	0.205	4.277

Note: *** implies significance at the 1% level.

4. Conclusion

Many firms in especially developed and developing economies have large amounts of intangible asset investments, mostly related to R&D activities. However, it is obvious that R&D investments and/or expenditures are neither properly recorded on financial statements nor fairly valued by the market. Furthermore, as R&D expenditure is treated as a current expense in the income statement, it may potentially have large effects on the asset side of the balance sheet and consequently on firm value.

This paper, in general, aims to test the value relevance of R&D expenditures and complementary assets on a quarterly time-series data regarding the R&D activities of Turkish manufacturing sector covering the period of 1992.Q1-2019.Q3. It contributes to corporate finance literature in several ways. First, it considers R&D intensity using two different proxies simultaneously in the same empirical research model. Second, it focuses on manufacturing sector as a medium low-technology or low-technology sector in innovation policy. Third, the empirical model is based on the market-to-book ratio, a forward-looking financial performance measure, as a proxy for firm value and the model is tested by advanced econometric methodologies by using a quarterly time-series data. Before proceeding to estimate the long-run cointegration coefficients that explain the relationships among the series, the presence of a unit root is tested by Augmented Dickey Fuller (1981) and, Zivot and Andrews (1992) tests. These test results indicate that series are stationary at their first differences. Following, one-break Gregory and Hansen (1996) cointegration test is employed to detect structural break in the cointegrating relationship among series. The results indicate the presence of a structural break date of 2005.Q1. Finally, dynamic ordinary least squares (DOLS) method of Stock and Watson (1993) is performed to estimate the long-run cointegration coefficients.

The estimated long-run coefficients indicate that considering the break date, R&D intensity variables have mixed effects on firm value (financial performance). Until the second quarter of the year 2005, the first R&D intensity variable as "the ratio of total R&D expenditures to net sales" had a statistically significant and positive effect on firm value, which then turned negative following the break date. However, the other R&D intensity variable as "the ratio of total R&D expenditures to total assets" fails to reveal any significant effect on firm value, both in the pre- and post-break date. The expected positive effect of the first R&D intensity variable is similar to previous findings of Chan et al. (1990), Doukas and Switzer (1992), Green et al. (1996), Hall (2000), Joseph (2001), Bae and Kim (2003), Xu et al. (2007), Tubbs (2008) and Chen et al. (2019). This finding may be associated with "the competition mitigation effect" of R&D intensity. As this effect enables the firm to distinguish itself from its competitors and prevents new market entrants, it may have created additional value. It is also empirically found that the positive effect of the first R&D intensity variable on firm value turned negative following the break date of 2005.Q1. The rarely observed negative effect as reported by Hartmann et al. (2006) and Wang et al. (2011) may be due to "the risk effect" of R&D intensity. The risk effect inherent in R&D investments and/or expenditures mostly lack producing any tangible asset, which may eventually destroy firm value.

The natural logarithm of complementary (tangible) assets as the control variable in the research model has statistically significant and negative effect on firm value until the break date and this effect reverses following the break date. The negative effect may be the result of independence between R&D activity and tangible assets as implicitly assumed by Lev and Sougiannis (1996), Eberhart et al. (2004), Ehie and Olibe (2010) and Li (2011). Moreover, the positive effect following the break date is also confirmed by studies of Teece (1986), Afuaf (2001), Lin et al. (2009), Bena and Li (2014) which conclude that firms with assets and/or capabilities complementary to R&D perform better than those lacking of such assets and benefit better from R&D.

The break date of 2005.Q1 can be associated with the time-lag effect of R&D activity as a result of several severe crises that the Turkish economy has experienced between 1999 and 2001. The time-lag effect of R&D activity on financial performance (and firm value) has been subject to studies of Bhagat and Welch (1995), Connolly and Hirschey (2005), Park et al. (2010), Zhou et al. (2011), Zhao and Xu (2013), Lee and Choi (2015), and Xu and Jin (2016). Findings of these studies indicate that though the lag length related to the impact of R&D activity on (various) financial performance (measures) may differ from current to third and more lag phases, the most outstanding effects are mostly observed in the second and third lag phases.

Peer-review: Externally peer-reviewed.
Conflict of Interest: The authors have no conflict of interest to declare.
Grant Support: The authors declared that this study has received no financial support.

Hakem Değerlendirmesi: Dış bağımsız.
Çıkar Çatışması: Yazarlar çıkar çatışması bildirmemiştir.
Finansal Destek: Yazarlar bu çalışma için finansal destek almadığını beyan etmiştir.

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