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R&D intensity, value appropriation and integration patterns within organizational boundaries

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ABSTRACT

Complementary insights from Transaction Cost Economics (TCE) and the Resource-Based View (RBV) of the firm are combined to predict the relationship between firm specific technological knowledge and patterns of integration within organizational boundaries. The findings show that the level of Research and Development (R&D) intensity (representing the creation of firm specific technological knowledge) has an inverted U-shaped relationship with the propensity of firms to integrate activities within organizational boundaries. At low levels of R&D intensity, firms' propensity to integrate their activities is low, but increases with escalating levels of R&D intensity in order to avoid the misappropriation of value generated by technological knowledge. However, beyond a certain R&D intensity level, the propensity to integrate activities declines, since the level of technological knowledge is high enough to prevent imitation by third parties. As expected we further find that firms which follow this integration pattern outperform those which do not. As the level of R&D intensity increases, the integration of production and marketing activities enables firms to improve performance until a certain R&D intensity threshold, after which such integration negatively affects performance.

1. Introduction

Various strands of the Transaction Cost Economics (TCE) literature have, either explicitly or implicitly, identified a relationship between the level of firm specific technological knowledge and the propensity of the firm to integrate operations within organizational boundaries (Williamson, 1975, 1985; Buckley and Casson, 1976; Rugman, 1981; Teece, 1986; Hennart, 1993). TCE scholars essentially argue that higher levels of proprietary technological knowledge increase the uncertainty and asset specificity of transactions (Williamson, 1975, 1985) and hence are more likely to lead to market failure in the exchange of such knowledge (or its outputs) outside the firm's boundaries.

The Resource-Based View (RBV) of the firm (Wernerfelt, 1984; Barney, 1991; Peteraf, 1993) infers a relationship between the level of firm specific technological knowledge and the ability of firms to ensure the inimitability of such knowledge in order to sustain competitive advantage. According to this view, while firms may contract out operations involving low levels of firm specific knowledge (Quinn and Hilmer, 1994), as the level of firm specific knowledge increases, integration of such knowledge may prove necessary in order to prevent its imitation (Quinn and Hilmer, 1994; Saviotti, 1998; Afuah, 2001). Nevertheless, we argue that very high levels of firm specific technological knowledge are expected to increase the inimitability of such knowledge (Barney, 1991), thus enabling

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firms to exchange firm specific technological knowledge with third parties without sacrificing their competitive advantage.

The current paper combines the TCE and RBV points of view by analyzing the relationship between firm investments in Research and Development (R&D) as a proportion of total sales (hereafter *R&D intensity*), the integration of activities within organizational boundaries and performance. Investment in R&D enables the creation and absorption of technological knowledge and is the major vehicle by which firms create firm specific technological knowledge (Hirsch, 1989; Mol, 2005; Almor et al., 2006), therefore, R&D intensity is employed in this paper as a proxy for the amount of firm specific technological knowledge contained in each unit of output. The central thesis of this paper is that the relationship between R&D intensity and the integration of operations is curvilinear.

The paper is organized as follows. First, we present a theoretical framework that shows how R&D intensity is related to the need to integrate or contract out organizational operations, and that links such integration patterns to expected performance. We then test the hypotheses derived from our theoretical framework using a sample of Israel-based firms. Finally, we discuss our findings and highlight their practical and theoretical implications.

2. Theoretical framework

Transaction cost economists have long identified market failure in inter-firm technological knowledge exchange as a salient reason for the integration of operations within organizational boundaries. Such market failure is often argued to be the result of opportunistic behavior by third parties who imitate the proprietary technological knowledge of a given firm and exploit it in ways that jeopardize this firm's ability to appropriate value from its knowledge (e.g. Williamson, 1975, 1985; Buckley and Casson, 1976; Rugman, 1981; Hennart, 1993). One of the important observations made by Teece (1986), for instance, is that, since innovating firms often operate in weak appropriability regimes, they mostly fail to appropriate value from the technological knowledge they create.

Williamson (1975, 1985) constructs of frequency, uncertainty and the asset specificity of transactions portray the relationship between the level of firm specific technological knowledge and the costs of exchanging this knowledge with third parties. Higher levels of firm specific technological knowledge are expected to increase the frequency of technological knowledge exchange within organizational boundaries and between the firm and its customers. Such knowledge exchange includes, among other things, the R&D unit transferring production specifications and operating instructions to the production floor and marketing unit, while, in parallel, receiving feedback on product design, costs and functionality from the production floor, distributors and customers (Teece, 1986; Hirsch, 1989; Casson, 2000; Douthwaite et al., 2001; Almor et al., 2006). The risk of opportunism by third parties grows with the frequency of technological knowledge exchange, hence creating pressures to integrate organizational activities within the firm's boundaries.

Higher levels of firm specific technological knowledge are further expected to increase uncertainty concerning technological exchange as it becomes harder to explicitly define contracts, since the nature of the transactions becomes too complex and uncertain to identify all contingencies (Williamson, 1985). Finally, higher proprietary technological levels increase asset specificity. Machinery, routines and skills become more dedicated and customized to a specific product when such a product is based on a high proportion of firm specific technological knowledge (Teece, 1986; Hirsch, 1989; Almor et al., 2006). Greater asset specificity is expected to increase the risks arising from opportunistic behavior (Williamson, 1975) and hence lead to integration of activities within organizational boundaries.

The RBV of the firm (Wernerfelt, 1984; Barney, 1991; Peteraf, 1993) presents a somewhat different explanation for a firm's propensity to integrate operations within organizational boundaries. The RBV essentially states that the possession of unique and inimitable firm specific technological knowledge is a source of sustainable competitive advantage. Low levels of firm specific technological knowledge are not expected to lead to a particular competitive advantage and can be therefore contracted out (Quinn and Hilmer, 1994). As the level of firm specific technological knowledge increases, its potential contribution to the creation of competitive advantage also increases. Thus moderate levels of firm specific knowledge often rely on the integration of operations within firms' organizational boundaries as means to make such knowledge more unique as well as prevent its limitability (Quinn and Hilmer, 1994; Saviotti, 1998; Afuah, 2001). However, at higher levels of firm specific technological knowledge the misappropriation of such knowledge becomes more difficult due to the increased cost involved for third parties to imitate such knowledge (Barney, 1991). As the level of firm specific technological knowledge increases, it is expected to become more unique and thus more difficult to imitate (Teece, 1981, 1986; Wernerfelt, 1984; Barney, 1991; Peteraf, 1993; Saviotti, 1998), thereby allowing a firm to withhold firm specific knowledge from other firms (Afuah, 2001). This, in turn, leads to high Ricardian- and quasi-rents stemming from the firm specific technological knowledge (Wernerfelt, 1984; Barney, 1991; Peteraf, 1993).[2] Even if imitation is possible to a certain extent, there is a resource advantage to innovators who have already built up strong positions in technological resources over imitators who need to catch up with this resource accumulation. As noted by Dierickx and Cool (1989), a strong initial technological position leads to a more rapid subsequent accumulation of additional technological resources compared to imitators. Furthermore, in many industries (albeit not all) higher levels of firm specific technological knowledge are expected to result in more patents, hence increasing the ability to prevent inappropriate use of this knowledge by other firms (Cohen et al., 2000; Kash and Kingston, 2001). The observa-

[2] Ricardian rents result from resource scarcity whereas quasi-rents refer to the relative added value a firm can extract from its resources compared to that of other firms.

tion that from a certain threshold on, higher levels of firm specific technological knowledge increase the inimitability of knowledge, implies that such high levels should also improve the ability of firms to appropriate value from their technological knowledge and that firms with very high levels of firm specific technological knowledge are more likely to contract out their activities without compromising their competitive advantage.

R&D intensity, defined as a firm's investment in R&D as a proportion of its total sales, is the major vehicle by which firms create firm specific technological knowledge as it portrays the investment share directed towards the creation and absorption of technological knowledge (Hirsch, 1989; Almor et al., 2006). Thus, R&D intensity is expected to be correlated with the amount of firm specific technological knowledge contained in each unit of output. Naturally, not all investments in R&D are likely to result in increased firm specific technological knowledge, however, on average, higher outlays on the creation of technological knowledge as a proportion of total sales are expected to result in higher levels of proprietary knowledge.

The level of a firm's R&D intensity, reflecting the level of firm specific technological knowledge it has attained, is pivotal to the ability of firms to appropriate value from this knowledge. Bearing in mind that the integration of activities within organizational boundaries entails high capital investments as well as high fixed and bureaucratic costs (Buckley and Casson, 1981; Teece, 1986; Jones and Hill, 1988), firms are unlikely to integrate their activities within their organizational boundaries unless such integration improves their ability to appropriate the value of their firm specific knowledge.

We argue that, at low levels of R&D intensity, firms base their operations on relatively simple technological knowledge. Such knowledge is usually generic and can be transferred to or purchased from third parties at a price close to its marginal cost since it is not likely to be subject to market failure. Low levels of R&D intensity imply that a firm's technological knowledge can be imitated easily and is unlikely to be source of competitive advantage. Therefore, there is little reason for firms to integrate their activities within organizational boundaries in order to protect this knowledge. Such integration will not prevent knowledge dissipation and will accrue high fixed and bureaucratic costs. For instance, it is not uncommon for apparel firms to buy designs from other firms, outsource the production of those designs and use outlets which are not part of their organizational boundaries to market their products. Thus, we conclude that contracting out activities allows firms with low R&D intensity to increase their profits (and created value) as it decreases operational costs.

As the level of R&D intensity increases, but is still moderate, both TCE and RBV logic indicate that firms are highly likely to integrate their activities within organizational boundaries. According to TCE logic, when the level of R&D intensity increases, firm specific technological knowledge is more likely to become subject to market failure due to the increased frequency, uncertainty and asset specificity associated with its transfer. RBV logic leads us to a similar conclusion as it implies that a moderate level of firm specific technological knowledge is not high enough to prevent its imitation (Saviotti, 1998; Afuah, 2001). Thus, at a moderate level of R&D intensity firms are expected to have a higher propensity to integrate activities within their organizational boundaries (relative to firms with low R&D intensity) in order to be able to appropriate the value of their firm specific technological knowledge.

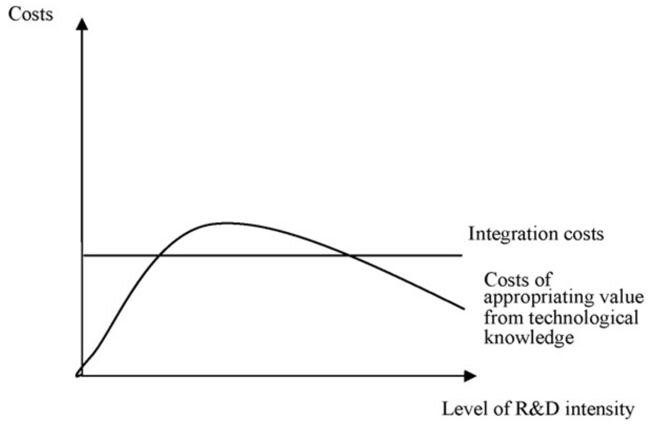

Chart 1. Relationship between the cost of appropriating value from specific technological knowledge and level of R&D intensity.

Nevertheless RBV reasoning further implies that even higher levels of R&D intensity grant firms the ability to appropriate the value stemming from their firm specific technological knowledge, as it becomes difficult to replicate such knowledge (Wernerfelt, 1984; Barney, 1991; Peteraf, 1993; Saviotti, 1998). This allows firms with high levels of R&D intensity to contract out at least some of their operations without facing a substantial risk of knowledge imitation (Katila and Mang, 2003), while enjoying a better cost position due to savings on upfront investments, fixed and bureaucratic costs. For instance, such firms may seek cooperation in complementary technological fields, while retaining core proprietary technology in-house (Hagedoorn, 1993, 1995; Cohen et al., 2000), and hence leverage their R&D activities through external knowledge sources (Stuart, 2000; Nicholls-Nixon and Woo, 2003; Spencer, 2003), or they may contract out production and marketing activities to third parties possessing complementary assets (Teece, 1986; Lavie, 2006). We posit that at high levels of R&D intensity, contracting out does *not* expose the firm to a real threat of knowledge imitation, while enabling it to reap a larger share of the economic value created by its firm specific technological knowledge due to savings on upfront investments and fixed costs.

Chart 1 summarizes the above arguments by depicting the relationship between the relative costs of appropriating value from firm specific technological knowledge and the costs of integrating activities within organizational boundaries, at different levels of R&D intensity.

The costs of appropriating knowledge-based value include "ongoing monitoring and control, potential renegotiation and litigation, and the costs associated with replacing the knowledge if the partner should misappropriate it" (Martin and Salomon, 2003: p. 358). For simplicity, we assume that the relationship between the cost of integration and R&D intensity is fixed.[3] At low levels of R&D intensity, value appropriation costs are lower than the cost of integration. These costs increase up to a certain level of R&D intensity, when the cost of contracting out exceeds that of integration (due to market failure in the transfer of such knowledge). As long as the net cost of contracting out is lower than that of appropriating the value of firm specific technological knowledge firms are expected to prefer contracting out to integration. However from the point where the cost of contracting out exceeds that of appropriating technological value integration is likely to be preferred. When R&D intensity becomes high enough to grant inimitability, the cost associated with contracting out starts to decline until it is once again lower than integration cost hence leading firms to prefer contracting out to integration once again. As a result we hypothesize that:

Hypothesis 1. There is an inverted U-shaped relationship between firms' level of R&D intensity and their propensity to integrate activities within their boundaries.

Assuming the existence of the hypothesized relationship between R&D intensity and the propensity to integrate activities within the firm, we further posit that firms which follow the proposed integration patterns should outperform those which do not. A fit between the proposed integration patterns and the level of R&D intensity is expected to maximize the value firms create, as it offers an optimal alignment between the costs of integration and those of appropriating value from firm specific technological knowledge (see Chart 1). Initially, at low levels of R&D intensity, contracting out should improve performance as it enables firms to reduce their fixed and bureaucratic costs, while value appropriation considerations of technological knowledge are expected to be only marginal. Then, up to a certain level of R&D intensity, integration of activities should increase performance since such integration enables firms to protect their technological knowledge and reap a larger share of the economic value created by this knowledge at a cost lower than that of value appropriation. Nevertheless, once a firm's R&D intensity passes a certain threshold, contracting out activities is likely to increase performance as it allows saving on the upfront investments and fixed costs incurred in integrated operations (Buckley and Casson, 1981; Teece, 1986), avoiding the bureaucratic costs associated with integration (Jones and Hill, 1988), as well as gaining access to additional sources of knowledge and complementary assets without facing a substantial cost of value misappropriation due to knowledge imitation. This leads us to hypothesize that:

Hypothesis 2a. The interaction between low to moderate levels of R&D intensity and the propensity on the part of firms to integrate activities within their boundaries *enhances* performance.

Hypothesis 2b. The interaction between moderate to high levels of R&D intensity and the propensity on the part of firms to integrate activities within their boundaries *reduces* performance.

3. Data

Our hypotheses were tested on a sample of 98 Israel-based, publicly traded, internationally oriented industrial firms.[4] The sample comprised two independent databases that were combined for the purpose of this study. One database included 52 firms out of 140 Israeli industrial firms that were traded outside Israel in the year 2000. Seventy five of the 140 firms were randomly approached to take part in an in-depth interview. The response rate of this group was about 69%. Basic comparisons between the 52 participating firms and the 23 non-participating firms did not show evidence of any non-response bias in terms of firm sales, number of employees, firm age, industrial classification or percentage of international sales. The second database included firms from the annual listing of Israel's 100 largest industrial firms (Dun and Bradstreet, 2000). The firms in the list were approached to take part in an in-depth interview. The response rate of this group was 58%. Basic comparisons between the 58 participating firms and the 42 non-participating firms did not show evidence of any non-response bias in terms of firm sales, number of employees, age of firm, industrial classification and percentage of international sales. Such bias was also excluded when we compared the characteristics of the two groups of firms that comprised our dataset.

The fact that Israel has a very small economy (GDP of US$ 123 billion in 2005, World Bank, 2007) implies that many Israeli firms target foreign markets. To avoid a bias stemming from differences in the integration patterns of firms that were mostly domestic (both in terms of the location of their operations and their target market) and those that were mostly internationalized, we included in our sample only firms that derived at least 25% of their sales from foreign markets. This procedure excluded eleven more firms, for which we have also refuted the possibility of a bias in terms of firm age, size and industrial classification. We have further omitted from the sample another firm due to lack of adequate data; thus our final sample size was 98 firms.

In both surveys, similar in-depth focused interviews were conducted with CEO- or VP-level executives. The interviews were based on structured questionnaires that were used to elicit the views of the interviewee, untainted by the interviewer's preconceptions to the extent possible. Both questionnaires included questions that covered a wide range of topics, including: general firm information, internationalization, innovation, alliances, competition, strategic characteristics and financial data. All the data concerned the fiscal year 1999.

The relevant variables for the current study were gathered from these questionnaires, and are detailed in Table A.1. When referring to organizational activities, we distinguish between the integration (and contracting out)

[3] Note that our arguments still hold for integration cost functions that decrease or increase monotonically.

[4] Government owned firms, which mostly operate in the defense industry were excluded from this study since it is practically impossible to collect data on such firms.

of R&D, production and marketing[5] activities, as these activities are often regarded as the major activities of firms in the context of this study (e.g. Porter, 1985; Teece, 1986; Sturgeon, 2002).

Descriptive statistics of the variables employed in this study are presented in Table 1 and show that the firms in our sample were fairly young and relatively small to medium sized in terms of number of employees, sales and assets. On average, the firms in the sample had a relatively high mean R&D intensity (27%) and invested heavily in marketing activities (on average 24% of sales). Most of the sales targeted the US and EU markets (35 and 29% on average) and the average international experience of the firms in our sample was 14 years. Table 1 also indicates that production and marketing activities were relatively less integrated within the organizational boundaries than R&D activities.

Basic correlations of the continuous variables presented in Table A.2 imply that the alternative size measures were correlated (number of employees, LAN of sales (Lsales) and assets). Lsales was also correlated with age, indicating that in our sample, larger firms were also older. Age was highly correlated with international experience, indicating a strong suspicion for multicollinearity. Age was also positively correlated with the percentage of sales in Israel, indicating that older firms in our sample were more domestically oriented. Marketing expenses as a percentage of sales (MRKT) were positively correlated with R&D intensity (RD) implying that the higher the R&D intensity, the higher their outlays on marketing activities. MRKT was also positively correlated with the percentage of sales in the US and negatively correlated with age, international experience and the percentage of sales in Israel. The percentages of sales in the US and in the EU were negatively correlated with the percentage of sales in all other areas. Return on Sales (ROS) was positively correlated with MRKT and with the percentage of sales in the EU, but negatively correlated with the percentage of sales in Israel, age and international experience.

Finally, the industrial classification of the firms in our sample was as follows: chemicals (5% of the firms), food and beverage (3%), metal (5%), rubber and plastic (6%), textiles and clothing (6%), computer hardware and electronics (25%), software (22%), telecommunications (16%), pharmaceuticals (5%) and other (7%).

4. Results

Hypothesis 1 posits an inverted U-shaped relationship between integration of activities within organizational boundaries and R&D intensity. We tested this hypothesis using binary logistic regressions in which the dependent variable (Int_i (i = R&D, production (P), marketing (M))) was 0 in cases where the firm contracted out parts of its R&D, production or marketing activities and 1 for full integration of each of these activities. The interviewees were specifically asked to refer only to strategically significant contracted activities and to ignore insignificant small-scale contraction of activities. Hence, integration means that a specific activity was performed by and large in-house. Consequently, the regression function used is shown in expression (1):

$$Pr\left(\text{Int}_i = \frac{1}{X}\right) = \frac{1}{1+\exp(-X\beta)}$$
$$= \left(1+\exp\left[-(\alpha+\beta_1\text{RD}+\beta_2\text{RD}^2+\beta_3\text{EMP}+\beta_4\text{AGE}+\beta_5\text{Sales\_US}+\beta_6\text{Sales\_EU}+\beta_7\text{Sales\_ROW}+\sum_{j=8}^{16}\beta_j\text{Ind}_j\right]\right)^{-1} \quad (1)$$

where β is the vector of coefficients and X is the matrix of explanatory variables. The first independent variable is R&D intensity (RD) and the second represents R&D intensity squared. Hypothesis 1 is supported if β_1 is positive (indicating increased probability of integration when R&D intensity increases) and β_2 is negative (indicating decreased probability of integration after a certain threshold of R&D intensity is passed).

The rest of the explanatory variables are control variables intended to control for alternative explanations for firms' integration patterns. The number of employees (EMP) in each firm is a proxy controlling for possible firm size effects. Economies of scale and scope are likely to indicate a greater tendency for larger firms to integrate their activities (Teece, 1986; Chandler, 1990). The associated coefficient, β_3, is thus expected to be positive.[6] The variable AGE controls for possible effects of firm age and accumulated experience on integration decisions. More experienced firms are expected to have the managerial capacity to integrate their activities (Chandler, 1990)[7]. Hence, its coefficient, β_4, is expected to be positive. The sales distribution variables (coefficients β_5–β_7) aim to control for regionally specific institutional effects (e.g. legislation and regulations, intellectual property rights regimes) on whether firms choose to enter such markets through integrated or non-integrated operations (Delios and Henisz, 2003). Finally, we control for possible industry effects (such as differences in regulation and intellectual property right regimes, labor and capital intensities, minimum efficient scale, demand) by using industry dummies. Controlling for industry affiliation is important since Levin

[5] Marketing activities include distribution, sales and customer support activities.

[6] Similar results were obtained when Lsales was used as a proxy for size.

[7] The variable IE was excluded from the regression since it was highly correlated with AGE. When AGE was replaced with IE in the regressions, weaker predictive results were obtained.

Table 1
Descriptive statistics, 1999

Variable	N[a]	Minimum	Maximum	Mean	Standard deviation
R&D intensity (RD), percentage	98	1	402	27	22
Age	97	3	66	17	15
Number of employees	97	15	950	276	238
Total sales (US$ thousands)	96	940	337,873	54,119	59,282
Assets (US$ thousands)	97	667	2,123,546	120,623	284,532
Operating profit (US$ thousands)	96	−140,818	96,923	1,047	22,626
Return on Sales	96	−1.10	1.00	.42	.26
Return on Assets	96	−1.00	17.56	.25	2.08
Marketing expenses to sales (MRKT), percentage	96	1	89	24	23
Percentage of sales in the US	92	0	97	35	24
Percentage of sales in the EU	93	0	90	29	20
Percentage of sales in the ROW	93	0	80	19	18
Percentage of domestic sales	94	0	75	17	24
International experience	96	1	59	14	13

	Frequency	Percentage
Integration of R&D		
Yes (1)	67	68.4
No (0)	31	31.6
Integration of production		
Yes (1)	57	58.2
No (0)	41	41.8
Integration of marketing		
Yes (1)	55	56.1
No (0)	45	43.9

[a] For some variables $N < 98$ due to missing values.

et al. (1987) and Cohen et al. (2000) report significant inter-industry differences in the ability to appropriate value.

The regression results are presented in Table 2 below, which show support for Hypothesis 1.

In all three regressions, the coefficient of RD is significant and positive and the coefficient of RD^2 is significant and negative. These results support the hypothesized inverted U-shaped relationship between R&D intensity and the probability that a firm will integrate various activities. Moreover, Table 2 indicates that the curvilinear relationship is at its steepest for R&D activities and is steeper for production than for marketing activities, implying that the strongest impact (positive or negative) of R&D intensity is on R&D integration, while its weakest impact is on marketing integration. The inflection point of all three curves is well within our sample range, hence further corroborating Hypothesis 1. Inflection occurs at RD = 36% for R&D, RD = 42.5% for production and RD = 43% for marketing, implying that the decrease in the probability that R&D will be integrated occurs at a lower level of RD than do the corresponding decreases for the integration of production and marketing.

As for the control variables, contrary to our expectation, AGE is shown to negatively affect the probability of integrating R&D and production within organizational boundaries. With respect to worldwide sales distribution, the firms that are most likely to integrate R&D activities are those selling principally to Europe, those that are most likely to integrate their production activities are those selling mainly to the rest of the world, while the firms that are most likely to integrate their marketing activities are those that sell primarily to the US. Firms selling largely to Europe are more likely to integrate R&D than firms selling mainly to other markets in the world. Firms that sell mostly to the rest of the world are more likely to integrate their production activities compared to the others, while those selling principally to the US are more likely to integrate their marketing activities. Industry effects on integration are significant mainly for the integration of production activities, with the probability of firms integrating their production activities being lowest for firms operating in the computer hardware and electronics industry and in the software and telecommunications industry. This result corroborates previous findings showing that, in these industries, production activities are considered less important for the creation of competitive advantages than other activities, and are therefore more frequently outsourced (Almor and Hashai, 2004). Pharmaceutical firms have a lower probability of integrating their marketing activities than other firms. A possible explanation for this result might lie in the large extent to which these industries export their products from Israel to the US and Europe (Central Bureau of Statistics, 2007). Israeli firms operating in these huge markets frequently seek production and marketing collaborations with large endogenous firms which facilitate their penetration to these markets by supplying domestic infrastructure and familiarity with local characteristics.

The binary logistic regressions have a fairly high explanatory power, as indicated by the −2 log likelihood test, the Cox & Snell and Nagelkerke pseudo *R*-square[8] tests and the high percentage of correct predicted estimates.

[8] Since the *R*-square statistic cannot be exactly computed for logistic regression models, these approximations are computed instead. Larger pseudo *R*-square statistics indicate that more of the variation is explained by the model, to a maximum of 1.

Table 2
Integration of R&D, production and marketing activities results of binary logistic regressions

Independent variables[a]	Dependent variables[a]		
	$Int_{R\&D}$ Coefficient (S.E.)	Int_{P} Coefficient (S.E.)	Int_{M} Coefficient (S.E.)
RD	.859** (.297)	.340** (.109)	.173** (.071)
RD^2	−.012** (.004)	−.004* (.002)	−.002* (.001)
EMP	−.012 (.009)	−.008 (.006)	.007 (.005)
AGE	−.103* (.085)	−.111** (.066)	−.048 (.039)
Sales_US	5.174 (3.280)	2.581 (2.356)	.384* (.136)
Sales_EU	10.917* (4.536)	2.791 (2.496)	.570 (2.329)
Sales_ROW	5.034 (3.151)	4.165* (.2.846)	−2.969 (2.010)
Food and beverage industry	−12.251 (26.579)	−19.334 (20.091)	−1.652 (2.222)
Metal industry	−15.782 (13.450)	−25.537 (20.057)	−2.328 (1.529)
Rubber and plastic industry	12.335 (14.350)	−46.859 (24.286)	−.731 (1.972)
Textiles and clothing industry	−15.278 22.071)	−45.852 (25.092)	−.910 (2.103)
Computer hardware and electronics industry	7.333 (1.351)	−24.961* (19.072)	−1.766 (2.169)
Software industry	8.734 (6.015)	−24.726* (21.103)	−1.500 (2.580)
Telecommunications industry	6.913 (6.106)	−26.787** (21.169)	−1.451 (2.198)
Pharmaceuticals industry	12.898 (2.556)	−23.562 (15.580)	−2.256** (2.827)
Other industries	7.494 (3.662)	−27.248* (20.198)	−1.500 (2.580)
Constant	−22.877 (13.540)	−21.028 (12.827)	−22.556 (20.827)
−2 log likelihood	33.12	55.56	79.39
Cox & Snell pseudo *R*-square	0.57	0.52	0.38
Nagelkerke pseudo *R*-square	0.80	0.70	0.51
Percentage of estimates predicted correctly	94.9	87.5	83.0
N[b]	93	93	92

S.E.: Standard error. **significant at $p < 0.01$; *significant at $p < 0.05$.
[a] See Table A.1 for description of variables.
[b] $n < 98$ due to missing values.

While the probability of reversed causality between R&D intensity and integration is low (since we obtain an inverted C-shape relationship when we switch the axes), we have refuted such suspicion of causality by replacing integration patterns (for R&D, production and marketing) with RD as well as with RD^2 in the above regressions. In all cases, we obtain insignificant regression results, as expected.

Hypotheses 2a and 2b examine the relationship between performance and the fit between the integration pattern chosen by firms and their level of R&D intensity. According to these hypotheses, we expect firm performance to be positively correlated with the interaction between R&D intensity and integration of activities, and negatively correlated with the interaction between R&D intensity squared and integration. We chose Operating Profit (Oprof), Return on Sales and Return on Assets (ROA) as three accepted alternative proxies for *performance* to test these hypotheses. Since data on the net revenues of the firms in our sample were not normally distributed, we used the ratio of operating profit to sales and assets as our ROS and ROA measures, respectively.

The general form of the regression equations used to test Hypotheses 2a and 2b is specified in expression (2):

$$\text{Performance} = \alpha + \beta_1 \text{RD} + \beta_2 \text{RD}^2 + \beta_3 \text{Int}_i + \beta_4 \text{RD} \times \text{Int}_i + \beta_5 \text{RD}^2 \times \text{Int}_i + \beta_6 \text{EMP} + \beta_7 \text{AGE} + \beta_8 \text{MRKT} + \sum_{j=9}^{18} \beta_j \text{Ind}_j + \varepsilon \qquad (2)$$

where α is the coefficient of the constant, β_i are the coefficients of the explanatory variables and ε is the error term. The independent variables in expression (2) are: R&D intensity (RD); R&D intensity squared (RD^2); dummy variables indicating whether each function is largely integrated or not i (Int_i, i = R&D, *production*, *marketing*); interaction variables indicating the impact on firm performance (over and above the main effects) of linkages between the integration of each function and R&D intensity ($RD \times Int_i$, i = R&D, *production*, *marketing*) and between integration and R&D intensity squared ($RD^2 \times Int_i$). These interactions test whether firms following the rationale of Hypothesis 1 achieve superior performance, as posited in Hypotheses 2a and 2b. Hence, the coefficients of the interaction of RD with integration patterns (Int_i) are expected to be positive, while the coefficients of the interaction of RD^2 with Int_i are expected to be negative. Other control variables aim to control for the effect of size (EMP) and accumulated managerial experience (AGE). The variables RD, RD^2 and MRKT control for the impact on performance of different levels of outlays on generating technological knowledge and on marketing activities (Barney, 1991; Peteraf, 1993).[9] Inter-industry performance variance is controlled by industry dummies.

Since Hypothesis 1 reveals a significant relationship between RD, RD^2 and the integration patterns of firms, Eq. (2) needed to be estimated in two stages to avoid multicollinearity. Hence, in the first stage, we estimated

[9] The variables RD and RD^2 were omitted from the regressions where integration of R&D activities is included in order to avoid multicollinearity.

the values of R&D, production and marketing integration patterns based on the results obtained in Table 1, and in the second stage these estimations were used to predict the various performance measures by stepwise Ordinary Least Squares (OLS) regressions.[10] An important concern in such estimation was to include at least one variable affecting Int_i (i = R&D, P, M) but not the performance measures (Kmenta, 1986). For each of the integration variables (Int_i) we identified such a variable, namely: Sales_EU for $\text{Int}_{\text{R\&D}}$, Sales_ROW for Int_{P} and Sales_US for Int_{M} (see Tables 2 and A.2).

The results of these regressions are presented in Table 3. The table presents three models for each of the three alternative performance measures, i.e. R&D integration patterns, production integration patterns and marketing integration patterns. Overall, the 9 models indicate that, when it comes to production and marketing activities, the anticipated inverted U-curve relationship exists between performance and the interaction of R&D intensity with the integration of either production or marketing activities. These results imply that, as the level of R&D intensity increases, the integration of production and marketing activities enables firms to improve performance. Nevertheless after a certain threshold, such integration has a negative performance effect, as predicted. When it comes to R&D activities, our regression results indicate a negative linear relationship between performance and the interaction of R&D intensity with the integration of R&D activities. We therefore conclude that Hypotheses 2a and 2b are supported only for production and marketing activities but not for R&D.

Based on the unstandardized coefficients we calculated the regressions' inflection points. Overall, for integration of production activities, performance starts to decline at RD = 17–19% (depending on the explanatory variable) while for integration of marketing, performance starts to decline at RD = 25–28%. These values are well within our sample range and indicate that contracting out production can increase performance at lower levels of R&D intensity than those that apply to the contracting out of marketing.

As for the control variables, high levels of R&D intensity (proxied by RD^2) mostly reduce performance measures, while even low levels of R&D intensity reduce Oprof. When Oprof and ROS are the dependent variables, MRKT positively affects performance. The only other variables that show significant values are the industry dummies. In general, firms from the software, telecommunications and pharmaceuticals industries outperform other firms, whereas for some performance measures, firms from the metal, plastic and rubber and "other" industries underperform. This result is consistent with Israel's comparative advantage in R&D intensive industries and Israel's overall export distribution, where software, telecommunication and pharmaceutical exports account for about 60% of the Israeli exports, excluding diamonds (Central Bureau of Statistics, 2007).

Overall, our performance measures yield solid regressions with adjusted R squares ranging between 0.18 and 0.59 and F statistics that are significant at least at the $p < .05$ level. We can exclude a possible multicollinearity bias in the regression presented in Table 3, since collinearity diagnostic analyses indicate that all Variance Inflation Factors (VIFs) are quite low. Heteroskedasticity is excluded since the plots of the residuals against the dependent variables show the residuals to be randomly distributed. Reverse causality between the interaction patterns and performance is also excluded by replacing performance with each of the interaction terms. These relationships are insignificant as expected.

5. Discussion and conclusion

This study combines insights from Transaction Cost Economics and the Resource-Based View of the firm regarding the relationship between firm specific technological knowledge (as reflected by firms' R&D intensity) and the integration of activities within organizational boundaries in order to allow for value appropriation and maximization of profits. TCE reasoning suggests a positive linear relationship between the level of firm specific technological knowledge and the propensity to integrate activities within organizational boundaries. Basing ourselves on RBV reasoning, we argue that the relationship has an inverted U shape; while the relationship between low to moderate levels of firm specific technological knowledge and the integration of activities is indeed positive, high levels of firm specific technological knowledge confer inimitability, which allow firms to contract out their activities, thus creating a negative relationship between the two at this stage.

As in analogous contexts (see for instance Männik and von Tunzlemann, 2005; Sorenson et al., 2006) we combine the predictions of TCE and RBV by viewing them as two structural forces leading to an optimal level of integration. We argue that, at low to moderate levels of R&D intensity, both TCE and RBV logic lead us to conclude that firms increase their propensity to integrate their activities in order to avoid the heightened transaction costs stemming from the increased uncertainty and asset specificity of transactions and the need to ensure the inimitability of their firm specific technological knowledge, which is a source for competitive advantage. However, at high levels of R&D intensity, we argue that firms are likely to reduce the propensity to integrate their activities as it becomes more difficult for others to imitate their firm specific knowledge, thereby following RBV reasoning.

Taken together, we show that the level of R&D intensity has an inverted U-shaped relationship with the integration of various activities within organizational boundaries. These findings extend the traditional TCE view regarding a positive linear relationship between the level of firm specific technological knowledge and the propensity to integrate activities, as they show that this linear relationship holds only to a certain extent and thereafter inverts, thus creating a curvilinear relationship.

[10] To check the robustness of our results, we have also used "forward" and "backward" regression procedures. These procedures did not change our results and the same variables were revealed as significant at $p < 0.05$. These procedures also enabled us to preserve a reasonable ratio between the sample size and number of explanatory variables.

Table 3
Performance, R&D intensity and integration patterns regression results (standardized coefficients)

	Oprof			ROS			ROA		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
RD		−.154*	−.134		−.053	−.055		.411	.410
RD^2		−.196*	−.186*		−.184*	−.183*		−.220*	−.221*
$Int_{R\&D}$	.021			−.013			−.037		
Int_P		−.005			.042			−.117	
Int_M			−.014			−.048			.113
RD × $Int_{R\&D}$	−.163*			−.025*			−.035**		
RD × Int_P		.020*			.034**			.059*	
RD × Int_M		.	.099			.038**			.189**
RD^2 × $Int_{R\&D}$	−.216*			−.180*			−.242*		
RD^2 × Int_P		−.026*			−.007**			−.025*	
RD^2 × Int_M			−.046			−139**			−158**
EMP	.043	.036	.037	.041	.020	.020	−.123	−.090	−.107
AGE	.036	.030	.032	.078	.070	.070	−.004	.023	.031
MRKT	.210*	.199*	.200*	.601***	.579***	.580***	.094	.065	.111
Industry									
Food and beverage	.019	.014	.014	−.068	−.055	−.056	.001	.022	.022
Metal	−.009	−.030	−.033	−.057	−.133*	−.133*	.009	.003	.005
Rubber and plastic	.035	.031	.028	−.013	−.016*	−015	.016	.039	.042
Textiles and clothing	−.008	.002	.001	.187*	.121*	.131	.006	−.003	−005
Computer hardware and electronics	−.065	−.061	−.058	−.090	−.081	−.078	−.018	.002	−.023
Software	.072	.072	.077	.413***	.388***	.378***	.019	.002	−.006
Telecommunications	−.071	−.067	−.167	.150	.137*	.133	.472***	.459***	.455***
Pharmaceuticals	.210*	.209*	.209*	.038	.034	.032	.045	.019	.037
Other	−.284*	−.285*	−.285*	.072	.084	.068	−.039	−.040	−.045
Adjusted R-square	0.28	0.28	0.29	0.57	0.58	0.59	0.19	0.18	0.18
ANOVA (F value)	5.96*	6.69*	6.66*	23.90***	37.21***	37.20**	8.92***	9.61***	9.60***
Maximal VIF	1.33	1.47	2.11	1.23	1.21	1.32	2.13	2.33	2.11
N	94	94	94	94	94	94	94	94	94

See Table A.1 for description of variables. Significant at $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; Oprof: Operating Profit; ROS: Return on Sales; ROA: Return on Assets; VIF: Variance Inflation Factor. *Note*: (1) $n < 98$ due to missing values; (2) Models 1, 4 and 7 relate to R&D integration patterns; models 2, 5 and 8 relate to production integration patterns, and models 3, 6 and 9 relate to marketing integration patterns.

Our findings are in line with the emergent stream of work regarding the governance and organization of global value chains (e.g. Sturgeon, 2002; Gereffi et al., 2005) as well as other findings regarding the increased propensity to outsource among R&D intensive firms (Mol, 2005). The findings further shed a different light on the observations of Kogut and Zander (1992, 1993), Martin and Salomon (2003) and others who contend that the level of firm specific technological knowledge is negatively related to the ability of firms to transfer such knowledge outside organizational boundaries. Our findings imply that firms with high levels of firm specific technological knowledge are able to codify at least part of their technological knowledge and transfer it successfully outside the firm's boundaries without loosing their ability to appropriate the value stemming from this knowledge (Balconi, 2002; Sturgeon, 2002).

This study also examines the performance of firms having different levels of R&D intensity that follow the integration patterns reported above. Our results show that the integration of production and marketing activities increases performance up to a certain level of R&D intensity, thus further supporting the notion that the integration of these activities at moderate levels of firm specific technological knowledge mitigates difficulties in appropriating value from such knowledge. Nevertheless, after a certain threshold of R&D intensity, integration of production and marketing activities decreases performance, probably since such integration entails higher investment, fixed and bureaucratic costs with no substantial contribution to performance. While we expected to find such a relationship also for the integration of R&D activities, our results showed a negative linear relationship between performance and the interaction of R&D intensity with the integration of R&D activities. A possible interpretation of this finding might be the characteristics of the firm's collaborators and the nature of inter-firm collaboration in production and marketing versus R&D activities. It might well be that, in the former case, production and marketing activities are contracted out to fairly large and established firms. Such firms are often expected to have the resources to capture the economic value of other firms' proprietary technological knowledge (Teece, 1986), with the result that at moderate levels of firm specific technological knowledge, collaboration is avoided. Hence, our arguments regarding the alignment between integration patterns and value appropriability are valid. This is certainly the case for many Israeli firms which collaborate with large endogenous enterprises in the US and Europe in order to successfully penetrate these markets. In the latter case, it might be that partners in R&D are not necessarily large firms, but rather are other small to medium-sized firms owning complementary technologies (Kleinknecht and Jeroen, 1992). Once again, this is often the case for Israeli firms that collaborate in research, development and design with other small to medium-sized Israeli firms from related technological areas. Such technological collaboration is facilitated by Israel's small size, which encourages knowledge transfer due to geographical proximity and the existence of social networks (Sorenson et al., 2006). This type of collaborating firms constitutes a lesser threat to a firm's ability to appropriate value from its proprietary technological knowledge, since their limited size and resource constraints make them less likely to capture other firms' profits from proprietary knowledge. In this case, complementary technological knowledge enhances performance as it increases the knowledge stock of interconnected firms (Afuah, 2001; Lavie, 2006).

It is noteworthy that the inflection points of the regression functions for the probability of integrating production and marketing activities (Table 2) are much higher than those of the regression functions for performance (Table 3). This implies that firms turn to contracting out at higher levels of R&D intensity than they should. This phenomenon could be explained by asymmetric information, implying that firms may be more concerned with value appropriation, and do not correctly evaluate their need for complementary assets (Teece, 1986). Hence, more research is needed to explain the dissonance between the descriptive and performance effects of integration patterns in order to further enhance our understanding of their underlying mechanisms.

Naturally, there are several limitations to this study. The study is based on a sample of fairly small to medium-sized firms from a single country. Hence, we are not able to comment on the relationship between the level of R&D intensity and integration patterns of large firms. It may well be, for instance, that large firms will be more likely to contract out some of their activities at any level of R&D intensity, as they are less concerned with the appropriation of value stemming from their firm specific technological knowledge than small firms (Rothaermel, 2001). In addition, the particular characteristics of Israel as the home base of the analyzed firms (e.g. Israel's relative distance from the large markets in North America and South East Asia) could certainly affect the observed integration patterns. Our findings refer only to a single year which does not necessarily signal when the profits from specific integration patterns occurred (due to a possible lag between the integration of an activity within organizational boundaries and the impact of such integration on performance or due to various year specific effects). Hence, replicating this study employing samples of larger firms, taken from several countries and utilizing data from several years would certainly enhance the external validity of our results. Moreover, integration patterns in this study were proxied using binary rather than continuous variables as measures for the extent of integration. For instance, the degree of ownership (Zhao et al., 2004) of each value adding activity should be a much more accurate proxy of integration patterns. A refinement of the integration proxies may increase the internal validity of our findings and may further expose the magnitude of the impact of different levels of R&D intensity on the integration patterns of firms. Our findings can also be further corroborated by referring to outputs of firm specific technological knowledge (e.g. number of patents) in addition to inputs (outlays on R&D). Finally, since our arguments build heavily on the notion of appropriability, it would be helpful to collect data on value appropriation mechanisms pursued by firms with different levels of R&D intensity, as well as on the characteristics of such firms' collaborators.

Overall, our results somewhat contradict Teece's (1986) view of the necessity of obtaining production and marketing assets in order to capture the profits from technological innovations. Our findings imply that high outlays on developing firm specific technological knowledge may serve as a substitute for investments in production and marketing operations. Firms may be better off if they increase their "technological depth" by investing in R&D activities before or in parallel to commercializing their products. Such investments should increase the probability of appropriating value from firm specific technological knowledge and reduce the extent to which substantial in-house production and marketing operations have to be owned.

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Appendix A

Table A.1
Description of variables

Variable name	Variable description	Measure	Notes
$Int_{R\&D}$	Performing R&D activities exclusively in-house	0 (no) 1 (yes)	'No' implies alliances or joint ventures in R&D
Int_P	Performing production activities exclusively in-house	0 (no) 1 (yes)	'No' implies alliances, licensing outsourcing or joint ventures in production
Int_M	Performing marketing activities exclusively in-house	0 (no) 1 (yes)	'No' implies alliances, licensing or joint ventures in marketing
RD	R&D intensity	R&D expenses as a percentage of total sales	From the firms' financial reports for 1999
RD^2	R&D intensity squared	$(RD)^2$	
EMP	Number of employees		From the firms' financial reports for 1999
AGE	Firm age	1999 minus year of establishment	
Lsales	Size of firm	LAN of firm sales	From the firms' financial reports for 1999
Assets	Value of firms assets		From the firms' financial reports for 1999
Oprof	Operating Profit		From the firms' financial reports for 1999
ROS	Ratio of operating profit to sales		From the firms' financial reports for 1999
ROA	Ratio of operating profit to assets		From the firms' financial reports for 1999
MRKT	Marketing ratio	Marketing expenses as a percentage of total sales	From the firms' financial reports for 1999
Sales_US	Percentage of sales in the United States	Percentage	As reported in questionnaires
Sales_EU	Percentage of sales in the European Union	Percentage	As reported in questionnaires
Sales_ROW	Percentage of sales in the Rest of the World	Percentage	As reported in questionnaires
Sales D	Percentage of sales in Israel	Percentage	As reported in questionnaires
IE	International experience	1999 minus the year of the first foreign sale	As reported in questionnaires
Ind	Industry classification		Ind1 = chemicals (reference industry); Ind2 = food and beverage; Ind3 = metal; Ind4 = rubber and plastic; Ind5 = textiles and clothing; Ind6 = computer hardware and electronics; Ind7 = software; Ind8 = telecommunications; Ind9 = pharmaceuticals; and Ind10 = others

Table A.2
Pearson correlations matrix

Variable[a]		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1) RD	Correlation	1	−.023	−.140	−.207	−.159	−.137	.179	−.065	.373**	−.114	.192	−.063	−.018	−.043
	Significance (2-tailed)	.	.834	.212	.184	.161	.234	.453	.554	.002	.322	.083	.633	.783	.644
	N[b]	98	97	97	96	97	96	96	96	96	92	92	93	94	96
(2) AGE	Correlation		1	.073	.194*	.055	.126	−.272*	−.159	−.425**	−.192	−.087	−.057	.362**	.931**
	Significance (2-tailed)		.	.495	.044	.678	.414	.032	.587	.000	.085	.435	.663	.001	.000
	N[b]		97	97	96	96	96	96	96	96	92	92	93	94	96
(3) EMP	Correlation			1	.684**	.345**	.085	.003	−.095	−.029	.074	.090	−.093	−.112	−.025
	Significance (2-tailed)			.	.000	.001	.497	.982	.372	.808	.514	.428	.388	.323	.895
	N[b]			97	96	96	96	96	96	96	92	92	93	94	96
(4) Lsales	Correlation				1	.731**	.088	−.183	−.163	−.219	.161	−.114	−.037	−.028	.119
	Significance (2-tailed)				.	.000	.397	.183	.551	.064	.148	.331	.823	.468	.244
	N[b]				96	96	96	96	96	96	92	92	93	94	96
(5) Assets	Correlation					1	−.036	−.135	−.055	−.114	.268*	−.137	−.062	−.146	.126
	Significance (2-tailed)					.	.804	.196	.576	.358	.013	.242	.584	.142	.827
	N[b]					97	94	96	96	96	92	92	93	94	96
(6) Oprof	Correlation						1	.158	.199	−.219	−.164	−.099	.129	.078	.124
	Significance (2-tailed)						.	.176	.061	.064	.565	.411	.312	.483	.334
	N[b]						97	96	96	96	92	92	93	94	96
(7) ROS	Correlation							1	.024	.654**	−.047	.236	.121	−.325**	−.344**
	Significance (2-tailed)							.	.977	.000	.744	.065	.277	.003	.002
	N[b]							96	96	96	92	92	93	94	96
(8) ROA	Correlation								1	−.045	.122	−.133	−.068	.134	−.034
	Significance (2-tailed)								.	.752	.262	.214	.531	.765	.695
	N[b]								96	96	92	92	93	94	96
(9) MRKT	Correlation									1	−.025	.453**	.224	−.499**	−.438**
	Significance (2-tailed)									.	.967	.000	.845	.001	.000
	N[b]									96	92	92	93	94	96
(10) Sales_US	Correlation										1	−.468**	−.375**	−.443**	−.191
	Significance (2-tailed)										.	.001	.000	.000	.100
	N[b]										92	92	92	92	92
(11) Sales_EU	Correlation											1	−.094	−.317**	−.155
	Significance (2-tailed)											.	.386	.003	.161
	N[b]											92	92	92	92
(12) Sales_ROW	Correlation												1	−.234*	.042
	Significance (2-tailed)												.	.038	.732
	N[b]												93	93	93
(13) Sales D	Correlation													1	.449**
	Significance (2-tailed)													.	.000
	N[b]													94	94
(14) IE	Correlation														1
	Significance (2-tailed)														.
	N[b]														96

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
[a] See Table A.1 for a description of the variables.
[b] $N < 98$ due to missing values.

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