

WILEY ENCYCLOPEDIA OF MANAGEMENT

THIRD EDITION

EDITOR-IN-CHIEF, PROFESSOR SIR CARY L. COOPER



VOLUME 13

TECHNOLOGY AND INNOVATION MANAGEMENT

EDITED BY V.K. NARAYANAN & GINA O'CONNOR

WILEY ENCYCLOPEDIA
OF MANAGEMENT

THIRD EDITION

VOLUME 13
TECHNOLOGY AND
INNOVATION
MANAGEMENT

Edited by

V.K. Narayanan and Gina O'Connor

University of Warwick and

University of Malta and Warwick Business School

WILEY

This edition first published 2014
© 2014 John Wiley & Sons Ltd

Registered office

John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

First published as a stand alone volume entitled *Encyclopedia of Technology and Innovation Management* in 2010 by John Wiley & Sons Ltd

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book. This publication is designed to provide accurate and authoritative information in regard to the subject matter covered. It is sold on the understanding that the publisher is not engaged in rendering professional services. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

The Publisher and the Authors make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation any implied warranties of fitness for a particular purpose. The advice and strategies contained herein may not be suitable for every situation. In view of ongoing research, equipment modifications, changes in governmental regulations, and the constant flow of information relating to the use of experimental reagents, equipment, and devices, the reader is urged to review and evaluate the information provided in the package insert or instructions for each chemical, piece of equipment, reagent, or device for, among other things, any changes in the instructions or indication of usage and for added warnings and precautions. The fact that an organization or Website is referred to in this work as a citation and/or a potential source of further information does not mean that the author or the publisher endorses the information the organization or Website may provide or recommendations it may make. Further, readers should be aware that Internet Websites listed in this work may have changed or disappeared between when this work was written and when it is read. No warranty may be created or extended by any promotional statements for this work. Neither the Publisher nor the Author shall be liable for any damages arising herefrom.

Chapters whose authors are US Government employees are © US Government in North America and © John Wiley & Sons in the rest of the world. The views expressed by those authors who are US Government employees do not necessarily reflect the views of the US Government Agencies they work for.

Library of Congress Cataloging-in-Publication Data is available
A catalogue record for this book is available from the British Library.

ISBN: 9781119972518; ISBN: 9781118785317 (online)

Typeset in 9.5/11 pt EhrhardtMT by Laserwords Private Limited, Chennai, India.
Printed and bound by TJ International Ltd, Padstow, Cornwall, UK.

Dedication

I would like to dedicate this edition of the *Wiley Encyclopedia of Management* to Professor Chris Argyris, who passed away last year. Professor Argyris and I were co-editors of the first edition, where we worked together, while I was on sabbatical, at Harvard Business School, to highlight the main structure, disciplines and functional areas of management that would be the template for future editions of the Encyclopedia. Chris was an outstanding scholar in management, probably the best known thinker in the field and renowned for his state-of-the-art management books and innovative management theories, but more important he was a wonderful person, who supported and nurtured all he worked with. I remember strolling with him on a number of occasions in Hyde Park, London, when he was in England, talking to him about his latest ideas and insights. Even in his eighties, he bubbled with enthusiasm. He was truly inspirational, and I, and his many colleagues worldwide, will miss him dearly.

*Professor Sir Cary L. Cooper, CBE
The Editor-in-Chief*

Preface

Technology and Innovation Management is emerging as a field unto its own. It has historically been scattered across multiple disciplinary fields, and indeed, in many universities, courses on the subject can be found in schools of management, engineering and even science. Likewise, the richness of the research agenda in the field has drawn scholars from many disciplines, including economics, psychology, sociology, and all functional areas of business. Defining the field is challenging not merely because of the complexity of the subject matter, but also because of its highly dynamic nature. But the concept of an encyclopedia of Technology and Innovation Management is surely a cue that scholars perceive a new field coalescing.

As a member of the encyclopedia series, this volume is an updated version of the earlier standalone Encyclopedia of Technology & Innovation Management originally published by Wiley in 2010. We have followed the same format with a few modifications. First, we gave each author the opportunity to revise his/her entry. As most entries were more or less current, there were only a limited number of changes. Second, we invited a few new entries, including frugal innovation and cloud computing. We also dropped the earlier version of web-based technologies. Third, we decided to treat the section on national innovation systems differently, including in the hard copy only the historical details of the NIS of a specific country, and moving the entire entry (including the specifics of the country's current NIS) to the online version. We expect the full version to change more frequently than the historical version, and the modifications can be made more easily in the online version than on hard copy version. In future volumes we expect the section on emerging technologies to be the source of the greatest change, as the numerous examples of interesting, novel technologies abound and begin to shape industries and create new types of competitive forces.

We would like to take the opportunity to thank Mary Malin, whom we found to be a patient, persistent, and truly pleasurable and professional editor.

We reproduce below the preface to the standalone volume.

In 2004, Rosemary Nixon approached one of the co-editors (V.K. Narayanan) with the idea of this encyclopedia as a volume in the Blackwell encyclopedia series, and Cary Cooper who was a major advisor for that series was very encouraging to move ahead. As a result of a merger, this volume is now published by Wiley. Knowing that this is a daunting task, Narayanan sought the help of Michael Hitt who identified Gina O'Connor who was willing and able to undertake the collaboration in editing this volume. Gina not only understood technology, but also brought marketing and project management experience to the endeavor. Together, they shared a passion for technology from different perspectives: strategy, marketing, and project management.

Our first task was to constitute a board of advisors; their names are listed in the beginning of the volume. We solicited two kinds of assistance from the board. First, we wanted them to critique the outline of topics thus preventing major gaps in our coverage of the topics in this volume. Second, we asked them for referrals, seeking prospective authors for various topics. The board's help eased our task considerably, and we want to record our deep gratitude for their assistance.

We generated the topics in three major steps. First, one of our then doctoral students (Yi Yang, currently a professor in the University of Massachusetts-Lowell) identified key words and authors from (i) major textbooks on Management Of Technology listed on the Technology & Innovation Management Division website of the Academy of Management, and (ii) articles written

in major technology journals from 2001 to 2004 (*Research Policy*, *IEEE Transactions in Engineering Management*), and also in major management journals (*Strategic Management Journal* and *Academy of Management Journal*). The keywords were tabulated by frequency and a frequently mentioned keyword was included in our original list of concepts. The author list gave us an initial roster of scholars to contact for entries about various concepts. Second, the editors sorted the chosen key words into clusters identifying major and minor concepts and identifying key words within them. Third, the draft of the major and minor concepts was circulated among the board members for their feedback, which led to revisions of the original list.

In order to highlight the dynamism of the field we included two sets of topics that are likely to be obsolete within three to five years: Emerging Technologies and Innovation at the National Level. The final structure of the encyclopedia reflects both the relatively enduring concepts and the elements in flux.

The topics formed the basis for contacting prospective authors, either directly or indirectly with the assistance of the board. Cumulatively, the authors represent the major contributors to the field of management of technology. Both editors spent considerable time reading the entries, making suggestions and proposing editorial changes, and in general streamlining and standardizing the entries to develop a coherent encyclopedia.

Inconsistencies with respect to terminology and definitions remain, but they are in our opinion a reflection of the diversity and vibrancy of the field. Rather than portraying TIM as a monolith, our approach has been to display the diversity of thought. In other words, when faced with the choice of insisting on consistency for its own sake, we have opted instead to allow the authors to describe their point of view. The editorial task was daunting and time consuming, but necessary. We can say with confidence that we learned a lot in the process, not merely about the art of editing, but about the field itself, through reading the entries of these authors.

An encyclopedia has many uses, but one that is often overlooked is something that struck us in the midst of the editing process – the use of these entries in the classroom. As we read the entries, we knew they represented up-to-date and easy to read material that can be assigned to students as and when relevant. Indeed this thought formed the basis of a professional development workshop in the 2009 Academy of Management Conference in Chicago. Both of us plan to use these entries in our classroom.

We owe a significant note of gratitude to many individuals. First, to our authors, without whom this work would not have seen the light of day. Second, to the board members who helped us in the critical early stages of the project and then along the way. Third, we owe a special note of gratitude to Yi Yang for research assistance in identifying the topics. Finally, to Rosemary, a pleasant, patient, soft-spoken editor who managed us well.

V.K. Narayanan and Gina O'Connor

About the Editors

Editor-in-Chief

Professor Sir Cary L. Cooper, CBE, is Distinguished Professor of Organizational Psychology and Health at Lancaster University Management School, UK. He is the author of over 100 books, Founding Editor of the *Journal of Organizational Behavior*, Founding President of the British Academy of Management, and Chair of the Academy of Social Sciences (comprises 46 learned societies and nearly 90,000 social scientists).

Volume Editors

V.K. Narayanan is the Associate Dean for Research, Director of the Center for Research Excellence, and the Deloitte Touché Stubbs Professor of Strategy and Entrepreneurship in Drexel University, Philadelphia, PA. During spring 1998, he held the Fulbright-FLAD Chair in Management of Technology at the University of Aveiro, Portugal. Most recently, Narayanan has been serving on the Academic Advisory Board of Project Management Institute. He was the (founding) Chair of the Strategy Process Interest Group at the Strategic Management Society. Previously, he had served as the Chair of the Teaching committee (2000–2001) and the Secretary-Treasurer of the Technology & Innovation Management Division of the National Academy of Management (1995–1998).

Narayanan has published five books. His book, *Managing Technology and Innovation for Competitive Advantage*, published by Prentice-Hall (2001), is a synthesis of his work over the last decade. His articles have appeared in leading professional journals such as *Academy of Management Journal*, *Academy of Management Review*, *Accounting Organizations and Society*, *Industrial Relations*, *Journal of Applied Behavioral Science*, *Journal Applied Corporate Finance*, *Journal of Applied Psychology*, *Journal of Management*, *Journal of Management Studies*, *Management Information Systems Quarterly*, *R&D Management* and *Strategic Management Journal*. Narayanan holds the bachelor's degree in mechanical engineering from the Indian Institute of Technology, Madras, the postgraduate degree in business administration from the Indian Institute of Management, Ahmedabad, and the Ph.D. in business from the Graduate School of Business at the University of Pittsburgh, Pennsylvania.

Gina O'Connor, Ph.D., is a Professor of Marketing and Associate Dean for Academic Affairs, in the Lally School of Management and Technology at Rensselaer Polytechnic Institute (RPI) in Troy, New York. She has held a number of leadership roles in the Lally School, including Director of the Severino Center for Technological Entrepreneurship (2010–2013), Director, Executive MBA program (Fall 2007–Fall 2008), and Director of MBA and MS Programs (Summer 2004–Summer 2006). Her fields of interest include new product development, breakthrough innovation in mature organizations, technology commercialization, and strategic marketing management in high technology arenas. The majority of her research efforts focus on how firms link advanced technology development to market opportunities, and how companies institutionalize management practices to enable breakthrough innovation.

Professor O'Connor held the Otto Monsted Guest Professorship at Danish Technical University in Copenhagen, Denmark, from September 2012 to March 2013. She has published numerous articles in a variety of academic journals including *Organization Science*, *Journal of Business Venturing*, *Journal of Marketing*, *Journal of Product Innovation Management*, *Harvard Business Review*, *Sloan*

xii About the Editors

Management Review, and others. Her work has won the Best Paper of the Year award four times in the *Journal of Product Innovation Management*, once in the *IEEE Transactions in Engineering Management*, and once nominated in *California Management Review*. She is coauthor of several books including *Radical Innovation, How Mature Firms Can Outsmart Upstarts* (HBS Press, 2000), and lead author of *Grabbing Lightning: Building a Capability for Breakthrough Innovation* (Jossey-Bass, 2008), which won the Strategy plus Business Magazine Innovation Award as one of four most influential innovation books for 2008.

Contributors

Céline Abecassis-Moedas

Católica-Lisbon School of Business and Economics, Lisboa, Portugal

Allan Afuah

University of Michigan, Ann Arbor, MI, USA

Matthew M. C. Allen

University of Manchester, Manchester, UK

Murugan Anandarajan

Drexel University, Philadelphia, PA, USA

John N. Angelis

Rochester Institute of Technology, Rochester, NY, USA

Bay Arinze

Drexel University, Philadelphia, PA, USA

Preeta Banerjee

Market Insights Deloitte Services LP, Waltham, MA, USA

Gloria Barczak

Northeastern University, Boston, MA, USA

Heidi M.J. Bertels

Stevens Institute of Technology, Hoboken, NJ and College of Staten Island (CUNY), New York, NY, USA

Bing Chen

Central University of Finance and Economics, Beijing, China

Yi-Yu Chen

New Jersey City University, Jersey, NJ, USA

Susan Cohen

University of Pittsburgh, Pittsburgh, PA, USA

Julian Cooper

University of Birmingham, Birmingham and Chatham House, London, UK

Robert G. Cooper

McMaster University, Hamilton, Ontario, Canada

Jeffrey G. Covin

Indiana University, Bloomington, IN, USA

James A. Cunningham

National University of Ireland, Galway, Ireland

Erwin Danneels

Worcester Polytechnic Institute, Worcester, MA, USA

Jenny Darroch

Claremont Graduate University, Claremont, CA, USA

Donna Marie De Carolis

Drexel University, Philadelphia, PA, USA

C. Anthony Di Benedetto

Temple University, Philadelphia, PA, USA

Patrick van der Duin

Delft University of Technology, Delft and Fontys University of Applied Sciences, Tilburg, The Netherlands

Thomas Durand

Le Cnam, Paris, France

John E. Ettlie

Rochester Institute of Technology, Rochester, NY, USA

xiv Contributors

George F. Farris

Rutgers University, New Brunswick, NJ, USA

Steven W. Floyd

University of St. Gallen, St. Gallen,
Switzerland

Kayano Fukuda

Japan Science and Technology Agency, Japan

José L. Galán

University of Seville, Seville, Spain

Rosanna Garcia

North Carolina State University, Raleigh, NC,
USA

Hans Georg Gemünden

Technical University Berlin, Berlin, Germany

William Golden

National University of Ireland, Galway, Ireland

Chittibabu Govindarajulu

Delaware State University, Dover, DE, USA

Jeffrey H. Greenhaus

Drexel University, Philadelphia, PA, USA

Abbie Griffin

University of Utah, Salt Lake City, UT, USA

Trudy Heller

Education for the Environment, Swarthmore,
PA, USA

Sean T. Hsu

Niagara University, New York, NY, USA

Mei-Chih Hu

Feng Chia University, Taichung City, Taiwan,
China

Mariann Jelinek

College of William and Mary, Williamsburg,
VA, USA

Van R. Johnston

University of Denver, Denver, CO, USA

Shalini Khazanchi

Rochester Institute of Technology, Rochester,
NY, USA

Peter A. Koen

Stevens Institute of Technology, Hoboken, NJ
and College of Staten Island (CUNY), New
York, NY, USA

Winston Koh

Singapore Management University, Singapore

Paul M. Kohl

Drexel University, Philadelphia, PA, USA

Rishikesha T. Krishnan

Indian Institute of Management Bangalore,
Bangalore, Karnataka, India

Donald F. Kuratko

Indiana University, Bloomington, IN, USA

Bárbara Larraneta

Pablo Olavide University, Sevilla, Spain

Christoph H. Loch

INSEAD, Fontainebleau, France

Raimo Lovio

Helsinki School of Economics, Helsinki,
Finland

Ta-Jung Lu

National Chung-Hsing University, Taichung,
Taiwan, China

John A. Mathews

Macquarie University Sydney, North Ryde,
New South Wales, Australia

Judy Matthews

Queensland University of Technology,
Australia

Robert McGowan

University of Denver, Denver, CO, USA

Shreefal Mehta

Rensselaer Polytechnic Institute, Troy, NY,
USA

Joana Mendonça

Centre for Innovation, Technology and Policy
Research, Instituto Superior Técnico, Lisbon,
Portugal

Morgan P. Miles

University of Tasmania, Tasmania, Australia

William L. Miller

4G Innovation LLC, Tucson, AZ, USA

Ram Mudambi

Temple University, Philadelphia, PA, USA

V.K. Narayanan

Drexel University, Philadelphia, PA, USA

Edward Nelling

Drexel University, Philadelphia, PA, USA

Gina C. O'Connor

Rensselaer Polytechnic Institute, Troy, NY,
USA

Pedro Oliveira

Católica-Lisbon School of Business and
Economics, Lisboa, Portugal

Paul Olk

University of Denver, Denver, CO, USA

Lois S. Peters

Rensselaer Polytechnic Institute, Troy, NY,
USA

Phillip Phan

Johns Hopkins University, Baltimore, MD,
USA

Kwaku O. Prakah Asante

Ross School of Business, Ann Arbor, MI, USA

Mark P. Rice

Worcester Polytechnic Institute, Worcester,
MA, USA

Patricia Robak

Drexel University, Philadelphia, PA, USA

Nadine Roijakkers

Hasselt University, Diepenbeek, Belgium

Marco Romano

University of Catania, Catania, Italy

Joshua L. Rosenbloom

University of Kansas, Lawrence, KS and
National Bureau of Economic Research,
Cambridge, MA, USA

Steve Russell

Siemens Corporate Research, Inc., Princeton,
NJ, USA

Robert Ryan

University of Pittsburgh, Pittsburgh, PA, USA

Søren Salomo

Danish Technical University, Lyngby,
Denmark

Don Scott-Kemmis

Australian National University, Canberra,
Australia

Kenneth L. Simons

Rensselaer Polytechnic Institute, Troy, NY,
USA

Svenja C. Sommer

HEC, Paris, France

Ashish Sood

Georgia State University, Atlanta, GA, USA

Sabrina Spatari

Drexel University, Philadelphia, PA, USA

J.-C. Spender

ESADE Business School, Spain, and Lund
University, Lund, Sweden

Clyde D. Stoltenberg

Wichita State University, Wichita, KS, USA

Tim Swift

St. Joseph's University, Philadelphia, PA, USA

Gerard Tellis

University of Southern California, Los
Angeles, CA, USA

xvi **Contributors**

Mark Tribbitt

Pepperdine University, Malibu, CA, USA

Wim Vanhaverbeke

Hasselt University, Diepenbeek, Belgium and
ESADE Business School, Barcelona, Spain and
National University of Singapore, Singapore

Daniele Virgillito

University of Catania, Catania, Italy

Liisa Välikangas

Helsinki School of Economics, Helsinki,
Finland

Judith L. Walls

Nanyang Technological University, Singapore

Jong-Wen Wann

National Chung-Hsing University, Taichung,
Taiwan, China

Chihiro Watanabe

Tokyo Institute of Technology, Yokohama,
Kanagawa, Japan

Christy H. Weer

Salisbury University, Salisbury, MD, USA

Carola Wolf

University of St. Gallen, St. Gallen,
Switzerland

Shaker A. Zahra

University of Minnesota, Minneapolis, MN,
USA

Maliha Zaman

Drexel University, Philadelphia, PA, USA

Paschalina Lilia Ziamou

City University of New York, New York, NY,
USA

Contents

Preface	ix
About the Editors	xi
List of Contributors	xiii
Absorptive capacity and technological innovation	1
Australia's national innovation system	5
Biotechnology: the technology of the twenty-first century	23
Cloud computing	39
Competitive dynamics in high-technology industries	47
Consumer interaction with novel interfaces: a typology of learning from product use	55
Continuing economic potential of nanotechnology	56
Cooperative R&D agreements (CRADAs)	73
Corporate entrepreneurship	75
Creating knowledge and innovation in the United Kingdom	83
Diffusion of innovation	87
Disruptive technology	91
Dual career ladders in organizations	93
Dutch innovation system: raising the lowland?	95
Emerging Web technologies	117
Evaluating innovation projects	126
Evolution of China's national innovation system and its challenges in technological development	132
Financing technology and innovation	151
Front end of innovation in large established firms	159
Frugal innovation	169
Generations of R&D and innovation management	171
Human resources in R&D	195
Indian innovation system	203
Innovation at the national level	214
Innovation-driven industry life cycles	223
Innovation models	233
Innovation teams	240
Intellectual property	246

viii Contents

Intellectual property strategy at the firm level	255
Japan's national innovation system	267
Learning and experience	287
Managing project–organization coupling in breakthrough innovation	293
National innovation system in Germany	301
National innovation system in Singapore	319
National innovation system in Taiwan	337
National innovation system of Finland	360
National innovation system of Ireland	374
National innovation system of Italy	388
National innovation system of the Russian federation	404
New-product development innovation and commercialization processes	412
Open innovation	419
Options and the analysis of technology projects	425
Organizing for innovation	427
Process innovation	437
Process innovation in operations	443
Project management under high uncertainty	455
Promoters and champions of innovation: barriers to innovation and innovator roles	466
Service innovation	473
Sources of innovation	486
Stage-Gate® product innovation system: from idea to launch	494
Sustainability as a guiding paradigm for prosperity	506
Technological characteristics of industries	519
Technological transition: S-curve or step-and-wait	522
Technology: discourse and possibility	523
Technology evolution	531
Technology forecasting	541
Technology intelligence in the era of open innovation	551
Technology strategy	565
Types of innovation	570
Understanding customer needs	579
University licensing	581
University–Industry–Government relationships	582
USA's national innovation system	583
User innovation	614
What are emerging technologies?	621
Subject Index	625

absorptive capacity and technological innovation

*Shaker A. Zahra, Bárbara Larraneta, and
José L. Galán*

Technological innovation is the foundation of competitive distinctiveness that leads to superior performance. Successful technological innovation often requires the integration of multiple capabilities. These capabilities are usually grounded in knowledge-based routines (Helfat and Peteraf, 2003; Nelson and Winter, 1982). The knowledge used to develop these routines could be internally developed or acquired from external sources (Larrañeta, Zahra, and Galán, 2012). The dynamism and complexity of today's competitive landscape makes it essential for companies to use the knowledge generated by other firms (e.g., suppliers and competitors) and institutions (e.g., university, research, and government laboratories). Determining the types of knowledge to bring into the organization, how to best assimilate this knowledge, and how to exploit it for competitive advantage are important decisions that are shaped by recipient companies' absorptive capacity (Lane, Koka, and Pathak, 2006). Companies that do not have this capacity may not benefit from the rich and varied knowledge that exists in their industry and markets (Lichtenthaler, 2009; Lichtenthaler and Lichtenthaler, 2010; Volberda, Foss, and Lyles, 2010).

THE CONCEPT AND ITS DIMENSIONS

Absorptive capacity refers to a firm's ability to "recognize the value of new external information, assimilate it and apply it to commercial ends" (Cohen and Levinthal, 1990). Recent

definitions of absorptive capacity highlight its power in converting the knowledge gained from external sources into usable ideas, products, goods, services, and models (Zahra and George, 2002; Zahra, van de Velde, and Larraneta, 2007). This process of knowledge conversion – the translation of abstract knowledge into more concrete prototypes, designs, and so on – makes it possible to exploit externally generated knowledge (Zahra, van de Velde, and Larraneta, 2007). As such, new conceptualizations of absorptive capacity underscore the need to exploit the knowledge gained externally or by integrating them with the firm's own knowledge base (Zahra and George, 2002).

The growing focus on knowledge conversion and its subsequent commercial exploitation adds richness to the literature that has traditionally focused on a firm's knowledge base. In one of the earliest discussions of absorptive capacity concepts, Cohen and Levinthal (1990, 1994) equated this capacity with a firm's R&D intensity, treating it as a static resource, not a capability. By definition, a capability embodies and integrates multiple skills and resources that enable the timely and efficient completion of a task (Helfat and Peteraf, 2003; Miller, 2003). A capability-based view implies learning and evolving. Learning means acquiring new knowledge and gaining new insights from its creation and use (Helfat and Peteraf, 2003). The more the organization and its managers learn, the more likely they will gain new insights about what they are doing and how to do it better. This learning is crucial because it helps managers to conceive of different strategic options, redefine the market arena, and reconceptualize cause-effect relationships differently. Equally important, this allows the firm to discover and pursue different

2 absorptive capacity and technological innovation

market opportunities (Zahra, 2009). These activities drive the firm's evolution. Thus, absorptive capacity is intimately connected to organizational learning, capability building, and organizational evolution (Lewin, Massini, and Peeters, 2011; Zahra, Sapienza, and Davidsson, 2006).

There are several conceptualizations of absorptive capacity (Cohen and Levinthal, 1990; Lane, Koka, and Pathak, 2006; Todorova and Durisin, 2007). Zahra and George (2002) propose that absorptive capacity has four dimensions: acquisition, assimilation, transformation, and exploitation. Each of these dimensions serves a unique purpose and thus can enrich the firm's technological innovation. A deficiency in one of these dimensions, however, can weaken the firm's overall innovation activities and hamper its ability to develop and commercialize innovative technologies.

As a key component of the firm's absorptive capacity, acquisition refers to the firm's ability to identify value and acquire externally generated knowledge that is critical to its operations. Identification of potentially valuable knowledge is usually based on a thorough understanding of the firm's opportunity set, strategy, and current product portfolios. It depends also on the nature of the firm's appreciation of the evolutionary forces that govern the markets and potential technological trajectories. Knowing who controls which types of knowledge and how to gain access to them is another important consideration that enables the firm to connect with these sources, developing beneficial relationships that facilitate knowledge transfer. Of course, the firm can rely on traditional market mechanisms to acquire this knowledge (e.g., through purchase or licensing).

Once knowledge is gained, the firm has to work hard at assimilating it. Assimilation refers to the mechanisms and routines a firm can use to process, interpret, and understand the information obtained from external sources (Kim, 1998). Assimilation makes it possible for the firm to proceed with transformation, which refers to a firm's ability to integrate, develop, and refine the routines that generate combinative or new knowledge (Garud and Nayyar, 1994). Finally, exploitation denotes a firm's ability to refine, extend, and leverage existing competencies by

incorporating acquired and transformed knowledge into its operations by developing strategic initiatives such as embarking on radical technological innovation (Zahra and George, 2002).

Over the past decade, researchers have attempted to refine and extend the Zahra and George conceptualization of absorptive capacity. For instance, Lane, Koka, and Pathak (2006) redefined the concept and Lichtenthaler (2009) empirically tested it as composed of three sequential learning processes: at two ends are explorative and exploitative learning and linking them is the transformative learning. At the core of this latter definition is the belief that the combination of the new knowledge with existing knowledge allows the firm to breed novelty that promotes technological innovation.

ABSORPTIVE CAPACITY AND TECHNOLOGICAL INNOVATION

Researchers have noted the importance of absorptive capacity for promoting and sustaining technological innovation (Escribano, Fosfuri, and Tribó, 2009; Zahra, 2009; Zahra and George, 2002). They suggest that incoming knowledge flows replenish the firm's knowledge base, thus infusing new ideas and processes that stimulate those activities associated with technological innovation. One weakness of prior research is failing to delineate when absorptive capacity can lead to radical versus incremental technological innovation (Lane, Koka, and Pathak, 2006). Incremental innovations are extensions, refinements, and upgrades of the firm's technology-based products, processes, and services. Radical innovations represent major advancements on what is known. As such, these innovations embody a variety of options that include truly new-to-the-world innovations and major technological shifts that qualitatively exceed what currently exists in the market.

A convenient way of conceptualizing the effect of absorptive capacity on technological innovation is to consider its breadth versus depth (Vasudeva and Anand, 2011). Breadth refers to the extent to which the knowledge contained in the firm's absorptive capacity is multifaceted and comprehensive in its coverage of a multitude of fields. As a result, absorptive capacity could be narrow (covering only a few fields)

versus broad (covering a wide range of fields). A broad absorptive capacity can give the firm a wider range of options when it comes to technological innovation. In contrast, depth refers to the extent to which the firm has developed an expert-type mastery of a particular technological domain. Depth could form a continuum ranging from shallow (where the firm has some or even a superficial level of skill in a given field) to deep (where the firm has great expertise in a given field). Plotting the orthogonal dimensions of depth and breadth provides some insights into the strategic value of absorptive capacity vis-à-vis technological innovation, as shown in Figure 1.

Quadrant 1 in Figure 1 shows the situation where the firm's absorptive capacity is narrow and shallow. This might occur from overspecialization, the absence of scanning systems that gather information about the competitive terrain, or the lack of sustained investments in R&D and other innovative activities. This situation is common in maturing and declining business divisions of larger corporations. Given its narrow and shallow absorptive capacity, the firm's product lines are apt to be limited, old, and even decaying. As a result, the firm's ability to engage in technological innovation is constrained. While the infusion of new external knowledge may help to some extent in reviving the firm's operations, the full benefits associated with knowledge inflows are not likely to materialize because of the company's limited absorptive capacity.

Quadrant 2 depicts the situation where the firm has knowledge in different areas but lacks

sufficient expert knowledge. The firm might benefit from the breadth of its absorptive capacity by being prolific in upgrading its products. Of course, sometimes a series of incremental innovations can lead to radical technological innovations.

In quadrant 3, the firm has deep knowledge in a few fields. This combination is conducive to pioneering technological innovations as well as building and protecting a viable niche. Over time, the growing depth of the firm's knowledge, however, could become a strategic handicap if the external environment changes drastically and a new technological paradigm emerges.

In quadrant 4, the combination of broad and deep knowledge could enrich the firm's technological innovation by providing opportunities for integrating and fusing technologies (Zahra, 2009), creating new product platforms, or adding more lines to existing products through upgrades. However, the firm's success in cultivating its absorptive capacity depends on its integrative capability. This capability refers to the firm's skill in managing and harvesting different sources of knowledge, assimilating them, and envisioning strategic uses for them. Another risk these companies face is the growing complexity of the organizational processing of different types of knowledge. Processing different strands of knowledge often fuels tension between the need to assimilate and connect different technological fields, and refining the skills to master the knowledge that the firm already has.

Breadth	Broad	2 Prolific incremental upgrades	4 Portfolio of radical & incremental innovations
	Narrow	1 Niche (upgrades)	3 Pioneering (Niche)
		Limited (Shallow) (Deep)	Depth Great

Figure 1 Depth versus breadth of absorptive capacity and technological innovation.