The Coevolution of International Scope and Technological Knowledge in MNCs

Geisler Asmussen, Christian; Hashai, Niron; Delios, Andrew

Document Version
Accepted author manuscript

Published in:
Journal of World Business

DOI:
10.1016/j.jwb.2021.101285

Publication date:
2022

Citation for published version (APA):
Geisler Asmussen, C., Hashai, N., & Delios, A. (2022). The Coevolution of International Scope and Technological Knowledge in MNCs. *Journal of World Business*, *57*(1), Article 101285.
https://doi.org/10.1016/j.jwb.2021.101285

The Coevolution of International Scope and Technological Knowledge in MNCs

Christian Geisler Asmussen
King's College London
Bush House, 30 Aldwych,
London, WC2B 4BG
Room S3.13
Email: christian.asmussen@kcl.ac.uk

Niron Hashai*
Arison School of Business
The Interdiscplinary Center Herzliya
Tel: +972-(0)52-3550067
Email: nhashai@idc.ac.il

Andrew Delios
Department of Strategy & Policy
National University of Singapore
1 Business Link
Republic of Singapore 117592
Phone: +65 6516-3094Fax: +65 6779-5059
Email: andrew@nus.edu.sg

* Corresponding Author

Paper accepted at the Journal of World Business

The Coevolution of International Scope and Technological Knowledge in MNCs

ABSTRACT

We explore *coevolution* in the growth of technological knowledge and international scope in multinational corporations (MNCs). We focus on technological knowledge and international scope because they are core to the performance of MNCs and because research has found that technological knowledge stimulates international growth, while internationalization stimulates technological growth. We address this seeming paradox by consolidating arguments about their growth under the coevolutionary umbrella. In so doing, we advance a novel coevolutionary argument: technological knowledge and international scope are *both* outcomes of interdependent, long-term strategic decisions aimed at optimizing the complementary effects of both dimensions on MNC performance. Accordingly, we develop a formal model of the *dynamic* processes by which technological knowledge and international scope coevolve. Our dynamic optimization model identifies four coevolutionary trajectories: (1) a trajectory in which growth in technological knowledge and international scope occur simultaneously; (2) a trajectory that has simultaneous reductions in both; (3) a trajectory in which technologically rich but domestically oriented firms expand international scope but reduce technological knowledge; and (4) a trajectory in which highly internationalized but technologically lagging firms expand technological knowledge but reduce international scope.

Keywords: technological knowledge, coevolution, international scope, internationalization, foreign direct investment.

1. INTRODUCTION

The relationship between the technological knowledge of multinational corporations (MNCs) and their international scope has been studied in two literatures. The first identifies how firm-specific technological knowledge facilitates international growth (Caves, 2007; Martin & Salomon, 2003; Morck & Yeung, 1991). by providing MNCs with competitive advantages that enable them to overcome liabilities of foreignness (Zaheer, 1995) when undertaking foreign direct investment (FDI). The second examines the impact of the international scope of MNCs on the acquisition of new technological knowledge (Lehrer & Asakawa, 2002; Liu & Buck, 2007; Liu & Zou, 2008; Salomon & Shaver, 2005; Von Zedtwitz & Gassmann, 2002; Zahra, Ireland & Hitt, 2000). This stream contends that international scope broadens the access of MNCs to foreign knowledge, which increases opportunities to acquire new technologies.

Alongside the literature on how MNCs expand international scope, other scholars have noted that MNCs at times divest FDIs (Benito, 2005; Berry, 2010; Kafouros, Cavusgil, Devinney, Ganotakis & Fainshmidt, 2021). Similarly, the technological development literature identifies how firms at times reduce technological investment and retreat in their levels of technological knowledge relative to the technology frontier (Berman, Down & Hill, 2002; Darr, Argote & Epple, 1995; Goto & Suzuki, 1989).

Putting these literatures together, we have four alternatives for growth: MNCs can expand their international scope or their technological knowledge while contracting the other dimension, they can expand both their international scope and technological knowledge or they can contract both their international scope and technological knowledge. Accordingly, we ask *"Are expansions and contractions in these two dimensions independent of one another, or do they coevolve"?* *Coevolution* refers to the question of whether the international expansion and technological development paths are interlinked and have common influences (Lewin & Volberda, 1999; Van den Bergh, & Stagl 2003; Cantwell, Dunning, & Lundan, 2010). It is imperative to consider coevolution to not only explore whether there can be a joint and interdependent development of both technological knowledge and international scope, but also to explicitly address how and when MNCs divest FDIs and retreat in their level of technology.

To develop our coevolutionary approach, we first consider research that has looked at reciprocal dependencies of international scope and technological knowledge growth (Berry & Sakakibara, 2008; Golovko & Valentini, 2011). Next, we consider theory that defines effectively why and how MNCs grow in technological knowledge and international scope (Birkinshaw, Hood and Jonsson, 1998; Berry & Sakakibara, 2008; Michailova & Mustaffa, 2012). However, we do not try to identify which is the ultimate antecedent. Instead, as coevolution emphasizes interlinkages in the evolutionary developments paths of international scope and technological knowledge developments, we join the two paths by establishing a common origin for their evolution in the assumption that an MNC's managers seek to maximize firm performance. Hence, in our perspective, MNC managers make decisions that balance investments in technological knowledge and international scope as coevolving positions that contribute maximally to the MNC's financial performance.

As such, our research evokes a coevolutionary perspective (Nelson & Winter, 1982; Levinthal & Myatt, 1994; Lewin & Volberda, 1999; Helfat & Raubitschek, 2000; Van den Bergh, & Stagl 2003; Cantwell, Dunning, & Lundan, 2010) of the relationship between a firm's technological knowledge and its international scope. The intuition behind our coevolutionary perspective is that MNCs with a given degree of international scope and/or technological knowledge can grow and improve performance by further internationalizing and expanding their technological knowledge base, as long as these two dimensions support each other to enhance firm growth. If an MNC becomes too focused on one growth path, its international scope will not be able to support further technological development, while its technological knowledge will not be able to support further international expansion, hence reducing firm performance. Such situations will require profit maximizing MNCs to retreat from their over-expanded path and redirect resources to the less expanded one. Since the competitive environment of the MNC changes over time, when there is a deviation from the optimal mix of international scope and technological knowledge, the MNC needs to react by rebalancing. However, shifting resources from one growth path to another is subject to adjustment costs imposing limits to the pace at which MNCs can switch from one path to another.

We formalize and test these ideas in a dynamic optimization model, which is an approach with a rich heritage in economics and finance, but is new to international business. In our model, we conceptualize the growth impeti of international scope and technological knowledge as emerging from interdependent choices made by forward-looking MNC managers seeking to maximize profit. Given this, we dynamically model interlinkages, interdependencies and complementarities in international growth and technological knowledge development. We test our model's predictions with panel data on 664 Japanese firms in the 1990 to 2009 period.

2. BACKGROUND LITERATURE

2.1 International expansion and technological advancement

A firm's knowledge stock is a central organizational resource for achieving competitive advantage (Grant, 1996; Kogut & Zander, 1992). Knowledge—especially technological knowledge—is a pre-condition for a firm's international expansion (Buckley & Casson, 1976; Kogut & Zander, 1993; Martin & Salomon, 2003) as it is a core basis for an MNC's superior competitive position (Caves, 2007; Hitt, Hoskisson & Kim, 1997) that provides an advantage to compensate for 'liabilities of foreignness' (Hymer, 1976; Zaheer, 1995).

Meanwhile, international scope enhances opportunities for technological knowledge acquisition, making knowledge acquisition a primary benefit of internationalization (Ghoshal, 1987). For example, Almeida (1996) has shown that foreign subsidiaries are more likely than domestic firms to source foreign knowledge. Hence, to select and retain (Nelson & Winter, 1982) geographically-bounded knowledge (Jaffe, Trajtenberg & Henderson, 1993) firms must expand abroad to be in the geographies where knowledge resides (Dunning, 1996) in the process of "knowledge asset seeking FDI (Buckley, Clegg, Cross, Liu, Voss & Zheng, 2007; Luo & Tung, 2007).

Accordingly, knowledge asset seeking FDI serves as a vehicle to transform and combine location-bound technological knowledge into new technological knowledge that is transferable within the firm (Berry, 2014). Thus, MNCs gain advantages by leveraging their international scope to acquire technological knowledge from their host countries (Asmussen, Pedersen & Dhanaraj, 2009; Cantwell, 1995; Nachum & Zaheer, 2005;; Von Zedtwitz & Gassmann, 2002).

An important consideration in understanding growth in international scope and technological knowledge is that expansions are indivisible in terms of the amount of resources required (Penrose, 1959; Wernerfelt, 1984). Growth in international scope or of technological knowledge tends to occur gradually. because of the limited ability of firms to successfully handle complexity in a tight time period (Hutzschenreuter & Voll, 2008; Vermeulen & Barkema, 2002; Wanger, 2004). Moreover, firms are constrained by "time compression diseconomies" (Dierickx & Cool, 1989) where bounded rationality (Cyert & March, 1963) limits the ability of managers to absorb and evaluate information. Given scarcity in managerial resources , managers can be cautious about the risks associated with substantial changes in their international scope and technological knowledge, and favor gradual change.

Gradualism is reinforced by demands for the simultaneous development of capabilities required for expanding the international scope and/or technological knowledge of firms. Rapid internationalization or substantial technological change absorb managerial time and effort (Barney, 1991; Penrose, 1959). As management teams are inelastic in the short term (Penrose, 1959; Tan & Mahoney, 2005), they are unable to handle the increased demands placed on them when required to make substantial changes to their firm's international scope and technological knowledge[1], leading to a preference for gradual expansion moves.

Finally, we must also consider that expansion is not a one-way path. The process of international growth involves both FDI and divestments (Benito & Welch, 1997), the net of which in a given time period, yields a firm's overall level of international scope. Firms re-balance their portfolio of FDIs in response to the performance of their subsidiaries (Duhaime & Grant, 1984, Markides, 1992) as well as market opportunities (Delios & Beamish, 1999; Bermini, Du & Jones, 2016, 2016; Berry, 2010). As such, divestment can mean that a firm is lessening its scope, to accommodate other investments and growth.

Meanwhile, we also know that technological knowledge and a firm's technologicial position vis-à-vis its competitors are not static. A firm's level of technological knowledge advantage is the extent to which its stock of codified and tacit technological inputs gives it a superior value or cost position compared to competitors (Besanko, Dranove, Shanley & Schaefer, 2010). Technological knowledge is not an absolute concept; it is defined relative to the technological frontier. The progression of this frontier over time is one reason why a firm's knowledge depreciates in the absence of reinvestment (Darr, et al., 1995). A firm's technological

[1] The recruitment of additional managers to address this constraint is often ineffective in the short term due to the time and attention that new managers require from current managers to become effectively embedded in existing firm specific routines (Penrose, 1959; Tan & Mahoney, 2005).

knowledge base further risks deterioration without reinvestment (Dierickx & Cool, 1989), as the knowledge required to compete in an industry changes over time (Reed & Defillippi, 1990). Hence, at times, firms may retreat in their technological knowledge relative to the technological frontier.

2.2 The coevolution of technological knowledge and international scope

Expansion and retraction in international scope and technological knowledge are core growth processes in an MNC. As such, research has examined international growth and technological knowledge development as simultaneous events in a firm. Berry and Sakakibara (2008) demonstrated that technological knowledge had a causal effect on international growth, but they did not find the reverse, concluding that a firm's international scope does not influence its technological knowledge acquisition. Their explanation centered on an idea that aligns with our coevolutionary arguments, in that the Japanese firms they studied did not possess sufficient managerial resources to integrate foreign knowledge sources to support technological knowledge advancement. Meanwhile, Golovko and Valentini (2011) argued that the two dimensions positively reinforce each other. Using a sample of early-stage internationalizing firms, they showed interlinkages: international scope promoted a firm's technological knowledge acquisition, and this new technological knowledge enabled firms to enter new foreign markets with novel products.

As such, coevolutionary processes are part of the expansion of an MNC's international scope and its technological knowledge base. Critically, given their interlinkages, expansion or retreat along one dimension may well influence choices along the other dimension from resource availability and capability development perspectives. This statement aligns with our point that technological knowledge and international scope coevolve. Critically, however, the forms that this coevolution process can take are more complex than bi-directional causality (Golovko and Valentini, 2011). We know little about the boundary conditions of the coevolution process as well as about how firms reach boundaries, or even what growth trajectories exist. As dictated by their resources, firms will have different trajectories for international scope and technological knowledge covolutionary expansion, with greater emphasis given to either international expansion or technological advancement, at different phases of their coevolutionary process. As such, we advocate an integrated approach. We model the *joint* effect of these relationships in a comprehensive temporal depiction of an MNC's growth and its performance.

3. THE DYNAMIC OPTIMIZATION MODEL

We derive our modeling approach from a method that has been used to understand how firms adjust their capital stocks over time (Dorfman, 1969; Gould, 1968; Lucas, 1967). This approach, which is called *dynamic optimization modeling*, has rarely been applied in international business, even though both international scope and technological knowledge are associated with a firm's capital stocks, as created by waves of successive investment and divestment. A dynamic optimization model is fit to study a firm's long-term, forward-looking strategic decisions about investments in international growth and technological development because it focuses on the complementarity of international scope and technological knowledge levels. In this complementarity, internationalizing firms can have a strong incentive to acquire technological knowledge and vice versa. These incentive effects are sufficient to drive expansion in either dimension and coevolution between them even in the absence of direct causal influences between technological knowledge and international scope.

Our dynamic optimization model makes two important advancements. First, it reveals a complex picture where diminishing returns to further expansion of international scope or technological knowledge lead to a substitution between the two. Hence, our dynamic optimization approach avoids assumptions of unidirectionality in associations between international scope and technological knowledge. It thereby better accommodates thresholds, limits, and substitutions in expansion. Second, we advance a truly dynamic perspective by avoiding the assumption that there is a given level of international scope or of technological knowledge, which then influences the preferred level of the other dimension. Instead, international growth and technological knowledge development are outcomes of interdependent strategic decisions of far-sighted managers, who consider the optimal levels of both international scope and technological knowledge when changing either dimension, as driven by the objective of maximizing firm performance.

In our model, a firm jointly chooses its trajectories of international growth and technological knowledge development to maximize a profit function of the form:

$$\pi = \int_{t=0}^{\infty} H_t\left(I, T, \dot{I}, \dot{T}\right) dt \tag{1a}$$

We note that the purpose of the model is not to predict performance; rather, the assumption of profit maximization is an instrument that allows us to predict the behavior of firms in terms of international scope and technological knowledge trajectories. In this profit function, π is the present value of a firm's accumulated profit streams over an infinite time horizon and H_t is the firm's discounted profit stream at time *t*. I_t denotes the firm's level of international scope, T_t is its level of technological knowledge (relative to the competitive frontier) at time *t*, while $\dot{I}_t = \left(\frac{dI}{dt}\right)_t$ and $\dot{T}_t = \left(\frac{dT}{dt}\right)_t$ represent the instantaneous rates of change in these two variables. We can make general assumptions about the discounted profit stream function H_t. In particular, as explained in detail below, we assume the function to exhibit diminishing returns to and increasing marginal costs in each of the state variables (such that $H_t{}''(I_t) < 0$ and $H_t{}''(T_t) < 0$); a positive interaction between the state variables ($d^2H_t/dI_t dT_t > 0$); and to include adjustment costs that are increasing exponentially in the rate of change in either state ($H_t'(\dot{I}_t) < 0$, $H_t'(\dot{T}_t) < 0$, $H_t''(\dot{I}_t) < 0$, and $H''(\dot{T}_t) < 0$). A simple way to parameterize these assumptions, which we will discuss, is to write it as:

$$\pi = \int_{t=0}^{\infty} \underbrace{e^{-pt}}_{\substack{\text{Discount}\\ \text{Factor}}} \Big(\underbrace{\alpha_1 I_t - \alpha_2 I_t^2}_{\substack{\text{International}\\ \text{Scope Effect}}} + \underbrace{\alpha_3 T_t - \alpha_4 T_t^2}_{\substack{\text{Technological}\\ \text{Knowledge Effect}}} + \underbrace{\alpha_5 I_t T_t}_{\substack{\text{Interaction}\\ \text{Effect}}} - \underbrace{\left(\alpha_6 \dot{I_t}^2 + \alpha_7 \dot{T_t}^2\right)}_{\text{Adjustment Cost}} \Big) dt$$

As seen here, the profit function comprises a discount factor, an international scope effect, a technological knowledge effect, an interaction effect, and an adjustment cost, each of which will be discussed now. The values of the parameters is an empirical question, to which we return to later.

Discount Factor. The factor e^{-pt} discounts the profit stream at time *t* with the discount rate $p \in [0,1]$. It is a standard way to model net present value in continuous-time models (Romer, 1986; Shone, 2002). Following established models, we assume that the discount rate is constant over time.

International Scope Effect. The term $\alpha_1 I_t - \alpha_2 I_t^2$ captures the effect of varying degrees of international scope on the firm's current profit stream, holding other factors, such as technological knowledge, constant. International growth confers both benefits and costs to a firm. The benefits come mainly in the form of additional revenue streams that the firm gains in foreign markets where it is able to utilize excess resources (Delios & Beamish, 1999). Other benefits include economies of scale and scope (Caves, 2007), reduced investment risk (Kim, Hwang & Burgers, 1993) and increased market power (Dunning & Rugman, 1985). The costs include tangible costs such as the opportunity cost of capital invested in foreign subsidiaries, the depreciation of this capital (requiring reinvestment), as well as intangible costs, such as heightened communication and coordination costs (Jones & Hill, 1988; Tallman & Li, 1996), and other costs associated with running an MNC's administrative structure.

The quadratic form of the expression implies that there are limits to the positive performance effects of international scope on firm profits, which is consistent with existing research (Hitt *et al.*, 1997; Contractor, Kundu, & Hsu, 2003; Lu & Beamish, 2004). Typically, the marginal benefits of further international expansion diminish at higher levels of international scope while marginal costs increase (reflected in $H_t''(I_t) < 0$). For example, after a firm has entered the countries that are closest to its home country, its subsequent choices are increasingly distant markets in terms of geographic, cultural, and institutional distance from its home country (Delios & Henisz, 2003; Johanson & Vahlne, 1977). As such, learning costs are steeper as the firm faces a higher liability of foreignness (Asmussen, 2009; Eden & Miller, 2004; Zaheer, 1995), and marginal revenues are lower than for early expansions. Further, increases in an MNC's international scope lead to an exponential increase in the number of interdependencies, creating higher communication and coordination costs that eventually exceed any international growth benefits (Tallman & Li, 1996; Tomassen, Benito & Lunnan, 2012). Further expansion into distant markets leads to diseconomies in managing large international operations (Bartlett & Ghoshal, 1999: 87), as the information-processing demands approach the capacity of a firm's managers and administrative systems (Hitt *et al.*, 1997). Finally, all else being equal, we can see that a wider international scope is more attractive at higher levels of α_2 and lower levels of α_2.

Technological Knowledge Effect. Mirroring international scope, the term $\alpha_3 T_t - \alpha_4 T_t^2$ captures a curvilinear effect of technological knowledge on a firm's current profit stream. Technological knowledge is a source of competitive advantage, as it provides a firm with a potentially superior cost or value position (Argote & Ingram, 2000; McEvily & Chakravarthy, 2002). At the same time, maintaining a competitive level of technological knowledge is costly as it requires continuous investments in Research and Development (R&D) to compensate for the fact that knowledge depreciates (Darr, et al., 1995) as it ossifies (Berman, et al., 2002), or becomes obsolete with new technological progress (Dierickx & Cool, 1989), or is imitated by competitors (Reed & Defillippi, 1990).

A curvilinear effect of technological knowledge on performance, which is captured by the quadratic form in our model, emerges from the diminishing marginal benefit and increasing marginal cost of maintaining a strong technological knowledge base (reflected in $H_t''(T_t) < 0$). The marginal benefits of technological knowledge diminish for several reasons. Industrial economists assume diminishing returns to product technological innovation (Klepper, 1996; Tirole, 1988) since, as noted by Ding, Ross, and Rao (2010:71), "as a product gets better, consumers may be less likely to detect improvement or find value in that improvement [and] therefore, the existence of an upper bound is an intuitively appealing assumption." Furthermore, product technologies are typically co-specialized with other resources within and outside the firm and these resources may be difficult to improve at the same rate as the core technology itself. Also, for investments in cost-reducing process knowledge, there are natural limits to how much costs can be driven down with technology—an idea inherent in the non-linear form of a learning curve (Darr *et al.*, 1995).

At the same time, the marginal cost of higher levels of technological knowledge vis-à-vis competitors increases. This is due to the opportunity cost of the capital invested as well as due to the effects of imitation and learning between firms. A large technological advantage over competitors creates incentives to imitate, leading competitors to innovate faster. To combat competition, aggressive investments are required by the leader to preserve its technological advantage. Aghion, Harris, Howitt, and Vickers (2001) capture this idea in a model in which technological followers innovate at a higher hazard rate than leaders, showing that there is a limit to the amount of technological knowledge that firms can profitably invest in and maintain. Furthermore, the value of knowledge depreciates over time. Given a constant depreciation rate, a higher level of previous technological knowledge level is associated with a higher rate of absolute depreciation, which necessitates a large reinvestment if a firm wishes to maintain its technological leadership position. In terms of our parameters, it is attractive to maintain a high level of technological knowledge if α_3 is high and α_4 is low.

Interaction Effect. If international scope and technological knowledge only influenced performance by their independent curvilinear effects, these choices could be treated as two independent optimization problems. However, the idea that technological knowledge enhances the returns to international scope, and vice versa, is well established (Caves, 2007; Lu & Beamish, 2004; Martin & Salomon, 2003), warranting the presence of an interaction term in the profit function ($d^2H_t/dI_t dT_t > 0$, parameterized as $\alpha_5 I_t T_t$). Technological knowledge provides competitive advantages (Delios & Beamish, 1999; Hitt *et al.*, 1997) and should allow MNCs to successfully penetrate foreign markets as well as derive high value from foreign resources (Bettis & Hitt, 1995). The development of technological knowledge often requires substantial investments in capital, time, and human resources (Dierickx & Cool, 1989). The return to these investments will be higher when such knowledge can be applied in multiple foreign markets (Morck & Yeung, 1997). Hence, the contribution of technological knowledge to performance is likely greater when it is deployed across a large number of foreign markets. In our model, a higher α_5 indicates a more important interaction and hence a stronger incentive for an MNC to balance between these complementary states.

Similarly, internalization theory suggests that technological knowledge is subject to market failure due to transaction costs in its buying and selling (Buckley & Casson, 1976; Campa & Guillén, 1999; Rugman, 1981). In the presence of market failure, the most efficient means to facilitate the cross-border exchange of knowledge is to internalize its exchange via the establishment of foreign subsidiaries. Yet, the logic of this argument also works in reverse. Hence, a corollary to internalization theory is that more internationalized firms, possessing more foreign subsidiaries, are likely to be more capable to exploit the value of their technological knowledge. High levels of international scope allow firms with high technological knowledge to generate abnormal returns through scale and scope economies and through the exploitation of market imperfections in the trade of such knowledge (Morck & Yeung, 1991).

Adjustment Cost. In the absence of constraints on adjustments to *I* and *T*, a rational firm would instantly choose the optimal levels of international scope and technological knowledge irrespective of its starting point at $t = 0$. Hence, there would be little dynamism in the proposed dynamic optimization model.

The firm's optimal position in the (*I*, *T*) space can be found by solving a joint maximization problem for the current profit rate; that is, maximizing H_t excluding the adjustment costs with respect to *I* and *T*. The First-Order Conditions (FOCs) for *I* and *T* are then $dH_t/dI_t = \alpha_1 - 2\alpha_2 I_t + \alpha_5 T_t = 0$ and $dH_t/dT_t = \alpha_3 - 2\alpha_4 T_t + \alpha_5 I_t = 0$, respectively, which solve for $I = (2\alpha_1\alpha_4 + \alpha_3\alpha_5)/(4\alpha_2\alpha_4 - \alpha_5^2)$ and $T = (2\alpha_2\alpha_3 + \alpha_1\alpha_5)/(4\alpha_2\alpha_4 - \alpha_5^2)$. These expressions demonstrate the interdependencies between the two dimensions, leading to their coevolution. In the absence of an interaction effect ($\alpha_5 = 0$), they reduce to $I = \alpha_1/2\alpha_2$ and $T = \alpha_3/2\alpha_4$; hence each state variable is chosen independently based on its own costs and benefits. However, once

$\alpha_5 > 0$, we can see that the optimal international scope is higher when the benefit to cost ratio of technological knowledge is higher, and vice versa.

Of course, and as captured in our coevolutionary discussion, firms cannot change their levels of international scope and technological knowledge as rapidly as they wish, as changes in either trajectory involve costs for both expansion and divestment (Moliterno and Wiersema, 2007). These costs are captured in our model by the term $(\alpha_6 \dot{I}_t^2 + \alpha_7 \dot{T}_t^2)$. This term is quadratic as we follow the literature and assume that it increases exponentially with the magnitude of the adjustment occurring within a given time frame, because large changes are disproportionately more complex and expensive than small changes (Dierickx & Cool, 1989; Vermeulen & Barkema, 2002). The assumption of convex exponential adjustment costs has been employed for decades (Abel, 1983; Gould, 1968). It is also plausible in the context of the relationships between international scope and technological knowledge development, as discussed earlier in our reference to 'time compression diseconomies' (Dierickx & Cool, 1989), where diminishing returns occur when the rate of change in a given time frame increases.

Change requires managerial attention, administrative effort, and time (Mahoney & Pandian, 1992; Penrose, 1959; Tan & Mahoney, 2007). A firm's managers must allocate substantial administrative resources for this task. Hence, when a firm enters a large number of new foreign markets or advances technologically within a short time span, time compression diseconomies will substantially increase the managerial costs of such efforts relative to a more moderate expansion. Moreover, we must consider managers limits in absorptive capacity and cognitive scope (Cohen & Levinthal, 1990). Constraints of absorptive capacity limit the capability of firms to rapidly expand their international reach and technological knowledge in a short time to fully capture their economic benefits. As it takes time to integrate new resources within a firm's existing routines and processes (Barkema & Schijven, 2008; Miller, Fern & Cardinal, 2007), firms that expand radically in a given domain within a short time period face more challenges than firms that expand at a more moderate pace (Knott, Bryce & Posen, 2003). Hence, extensive changes have convex adjustment costs – the marginal cost of expansion increases when the rate of expansion is accelerated (Knott *et al.*, 2003:193).

3.1 Optimal international scope and technological knowledge development paths

The objective of the firm is to choose trajectories of I and T that maximize the present value of its profit stream as given in Equations (1). This is an unconstrained maximization problem in the sense that the firm can choose any I or T at any point in time, but the convex adjustment cost will limit the rates of change that can profitably be pursued and hence provide an implicit constraint on the firm's actions. We derive the formal solution to this problem in the Appendix. It is computationally complex and cannot be solved for a closed form solution with general parameter values, but we can arrive at a solution by, in the first instance, restricting the parameters (without loss of generality) such that all $\alpha = 1$ and $p = 1/2$. Later we will graphically explore the comparative statics of the parameters. With these assumptions, the resulting optimal rates of change at a given point in time (normalized to $t = 0$) becomes:[2]

$$\dot{I}_0 = \tfrac{dI}{dt}(0) = \tfrac{1}{2} - \tfrac{3}{4} I_0 + \tfrac{1}{4} T_0 \quad (2)$$

$$\dot{T}_0 = \tfrac{dT}{dt}(0) = \tfrac{1}{2} - \tfrac{3}{4} T_0 + \tfrac{1}{4} I_0 \quad (3)$$

As these equations show, the change in the two variables is decreasing in the level of the variable itself but increasing in the other variable. These equations can be used to estimate the 'steady states' of the model by setting them equal to 0 and solving for I and T:

---

[2] The intercept and slope coefficients in these equations are results of the unitary parameters in Equation (1), but will be estimated empirically later.

$$\dot{I}_0 = 0 \Leftrightarrow I_0 = \tfrac{2}{3} + \tfrac{1}{3} T_0 \qquad (4)$$

$$\dot{T}_0 = 0 \Leftrightarrow T_0 = \tfrac{2}{3} + \tfrac{1}{3} I_0 \qquad (5)$$

Equation (4) describes the steady states of *I*; that is, the combinations of *I* and *T* at which the firm will have no incentive to make changes to its level of international scope. Equation (5) shows the steady states of *T* where no changes will be made to technological knowledge. When both equations are fulfilled simultaneously, the firm has no incentive to make an adjustment in either dimension—a situation that we define as the overall steady state. Confirming our earlier analyses, the only values of *I* and *T* that satisfy both of these equations are $I = T = 1$, which is what is obtained by substituting $\alpha = 1$ into the static optimization solution decribed earlier. Hence, reassuringly, the firm's optimal position in the (*I*, *T*) space coincides with the endpoint of the optimal trajectories: it is the only steady state at which this firm will not seek to change *I* or *T*.

To obtain a graphical representation of both the optimal rates of change at each point as well as of the steady states, we plot the phase diagram in Figure 1. In this figure, the solid black line traces the steady states of *T* (Technological Knowledge) and the dotted black line traces the steady states of *I* (International Scope), both of which have intersections of $\tfrac{2}{3}$ as shown in Equations (4) and (5). The gray arrows, the length and direction of which is generated by simulating the model based on Equations (4) and (5), represent the trajectory streams that firms follow given certain positions in (*I*, *T*) space.

*** Figure 1 about Here ***

As the figure demonstrates, an interesting implication of the model is that firms alternate between periods with positive and negative adjustments to *I* and *T*. For example, as indicated by the arrows in Figure 1, a 'global explorer' will initially reduce its international scope, even when it already has a level of international scope *below* the steady state, and only later when its increased technological knowledge pushes it into the 'virtuous cycle' area, does it begin to expand internationally again. Although this form of behavior seems counterintuitive, it is a logical result of managers considering the interdependence between the two dimensions. Given a low initial level of technological knowledge, it is too expensive to maintain a high level of international scope in the short term (presumably, such a firm would struggle to be competitive with technologically superior rivals in foreign markets). As another example, a 'domestic exploiter' initially increases its international scope, even in the case when it already has a level of international scope *above* its steady state. The intuition is that such a firm already has an unsustainably high level of technological knowledge, and it is seeking to exploit this knowledge in global markets as a 'cash cow' while it can.

3.2 Theoretical implications of the model

The phase diagram in Figure 1 illustrates four distinct trajectories, each based on a firm's starting point. We label them as (1) virtuous cycle, (2) domestic exploiter, (3) global explorer, and (4) overstretching.

Virtuous cycle. In the central band between the solid line and the dotted line, the firm is in a balanced, self-reinforcing state in its levels of international scope and technological knowledge. The firm uses its technological knowledge to overcome its liability of foreignness and compete successfully in international markets. It has an incentive to expand its global footprint to more efficiently exploit its technological knowledge. This global footprint, in turn, provides it with opportunities to capitalize on its technologies, while also giving it an incentive to invest in acquiring new technological knowledge. Nevertheless, there is a limit to this cycle, as the firm's motivations for continued technological and international expansion diminish as it approaches the steady state at the intersection. Since firms in the virtuous cycle band exhibit a positive association between their international and technological expansion, the virtuous cycle corresponds to the situation depicted by most prior research on international scope and technological knowledge, in which increased levels of one leads to expansion in the other. For example, it captures the trajectories of the early stage firms described by Golovko & Valentini (2011). However, in our study, the motivation for the positive association between the two dimensions is different: it is derived from the complementarity in the effect of international scope and technological knowledge on firm performance.

Domestic exploiter. In this area, the firm has a strong technological knowledge but a bias towards domestic operations (the upper-left area in Figure 1). Such a firm will tend to internationalize rapidly to exploit its technological knowledge. Initially, it will lose some of its technological advantage relative to other firms, because it does do not have a sufficient international presence to fully exploit its technological knowledge and, therefore, lacks an incentive to reinvest in it and maintain it. However, as it approaches the middle of the figure, it crosses to the right of the solid line, at which point it will begin to refocus on increasing its technological knowledge, as it now follows the virtuous-cycle path. This domestic exploiter area represents a typical international growth process for firms that initially possessed a technological advantage, as captured in traditional international growth models that emphasize how technological advantages initially motivate international expansion (Buckley & Casson, 1976; Caves, 2007).

Global explorer. A firms that finds itself in the bottom-right area of Figure 1 is highly internationalized but possesses weak technological knowledge. In this area, it will face competitive pressures that come from its lack of technological knowledge, and might be forced to retreat gradually from its international position to develop an emphasis on investing in technological knowledge development to improve its competitive position. By doing this, such a firm will gradually catch up with technologically superior international competitors (moving up and to the left in the figure). However, after it has acquired sufficient technological knowledge (as it crosses above the dotted line), it will again begin to increase its degree of international scope. The global explorer provides a new perspective on processes of 'de-internationalization' (Benito & Welch, 1997; Bermini, et al., 2016) in which firms divest international operations to refocus their strategy. It also complements existing literature on emerging market MNCs (Duysters, Jacob, Lemmens & Yu, 2009; Luo & Tung, 2007; Mathews & Cho, 1999; Mathews, 2006), which emphasizes that these MNCs did not have a technological advantage when first entering foreign markets, but do seek to develop such after initial entries into foreign markets.

Overstretching. A firm may experience contractions in both dimensions if its levels of technological knowledge and international scope are too high. In this state, the technological knowledge of the firm cannot support further profitable international expansion, while its level of international scope does not allow it to exploit or explore new technological knowledge (March, 1991). Such a firm is in a state of constrained resources, where the costs required to maintain existing levels of technological knowledge and international scope exceed the combined benefits. By reducing levels of technological knowledge and international scope, an overstretched firm adjusts back to sustainable levels as it approaches the equilibrium.

3.3 Comparative statics

We now examine the impact of some of the parameters of the model, in particular the discount rate (p) and the degree of interdependence (α_5).

Discount rates. Our closed-form solution to the model was based on $p = \frac{1}{2}$, but it is possible to estimate a solution for any numerical discount rate and use that solution as the basis for a new phase diagram, similar to what we depict in Figure 1. This exercise[3] reveals that changes in the discount rate change the magnitude of the coefficients slightly, but does not alter their signs. This outcome is evident from Figure 2, which demonstrates the graphical solution to the model for a far-sighted firm with $p = \frac{1}{10}$ (the solid lines), as well as for a myopic firm with $p = \frac{9}{10}$ (the dotted lines).

*** Figure 2 about Here ***

Figure 2 shows that seemingly large changes in the discount rate actually have little bearing on the relative positions of the four areas. For a myopic firm; that is, a firm with a high discount rate that is more concerned about current rather than future levels of international scope and technological knowledge, the global explorer and domestic exploiter areas become slightly larger, suggesting that such a firm will be more likely to engage in the trading off of one dimension against the other. However, more than affecting the types of changes that firms make, the discount rate affects the speed at which a firm makes changes, as the time value of money influences the trade-off between current adjustment costs and future product-market profit streams. For example, it can be shown that, for a firm with $p = \frac{1}{2}$ the optimal initial change is 0.5 in both dimensions, whereas a more far-sighted firm with $p = \frac{1}{10}$ would have an initial rate of change of ~0.66, as it is willing to bear higher adjustment costs today in return for being at a better position in the (I,T) space tomorrow. Similarly, a more myopic firm with $p = \frac{9}{10}$ would expand more slowly towards the optimum.

*Degrees of Interdependence***.** The curvature and speed of a firm's trajectories also depend on the coefficients on I and T. In the closed form solution, we assumed all α to be 1, which implicitly corresponds to an assumption that there is a balance between the direct effect of the individual states and the effect of their interaction. However, it is possible to graphically (if not analytically)

[3] All numerical simulations in this paper were implemented in Mathematica version 12.0.0.

estimate the model with different coefficients and, in particular, with different degrees of interdependence between the two dimensions, as shown in Figure 3.

*** Figure 3 about Here ***

Panel (a) of Figure 3 is based on a model with a low coefficient on the interaction term ($\alpha_5 = 0.1$) and high coefficients on the direct effect of each dimension ($\alpha_1 = \alpha_3 = 1.9$). In this case, the two dimensions become largely independent choices, and the state of one variable has little influence on changes in the other, thereby reducing the type of behavior described above. In panel (b), conversely, we can see that a high coefficient on the interaction term ($\alpha_5 = 1.9$) and low coefficients on the direct effects ($\alpha_1 = \alpha_3 = 0.1$)—in other words, a larger mutual interdependence between the two trajectories—leads the 'virtuous cycle' band as well as the 'overstretching' band to become narrower while the 'global explorer' and 'domestic exploiter' areas become larger. In this case, the two dimensions are highly co-specialized (Teece, 1986) and the firm will suffer from having an 'unbalanced' relationship between them, leading to the general tendency for most firms to trade off one dimension for the other.

3.4 Empirical implications of the model

We test the predictive validity of our model by analyzing its empirical implications. We start our consideration of the model from the signs in Equations (2) and (3), which predict the adjustments that firms make, based on their levels of international scope and technological knowledge. First, we can see from these equations that the higher the level of *I* (*T*), the lower the adjustment to *I* (*T*). Hence, changes in a given variable are slower the greater the starting value of that variable. Second, we can see from these equations that the higher the level of *I* (*T*), the higher the adjustment to *T* (*I*), and vice versa. That is, the level of each variable has a positive effect on the adjustment to the *other* variable: a high level of technological knowledge results in greater benefits from greater international scope, and vice versa, reflecting the complementarity of international scope and technological knowledge.

We use these ideas as the basis for our tests. We develop an econometric equivalent of Equations (2) and (3), recognizing that the magnitude of the coefficients, rooted in the underlying α, is an empirical question. Furthermore, an important step is to recognize that a number of factors outside of our model might influence the changes and states of the variables, and that a reliable empirical estimation rests on our ability to control for those factors. First and foremost, we can expect that firms differ in ways beyond their states of I and T. These differences may lead them to expand or retreat differently. For example, some firms may have more resources that improve their ability to acquire new knowledge or do FDI, and barriers to and opportunities for growth may vary across industries. To reflect this, we let the constants in equations (2) and (3) be influenced by a vector of a firm-specific control variables **C** and by industry fixed effects of F_I and F_T, for the two equations. Second, with an evolving technological landscape and varying rates of globalization, it is likely that the steady state will be a moving target. As such, we add year fixed effects Y_I and Y_T.

We must also consider that our theoretical model is in continuous time, but our firm-level data are measured at discrete points in time (years). Accordingly, we use discrete changes rather than instantaneous changes as dependent variables. We thus define firm i's change in international scope at time t as $\Delta I_{it} = I_{it} - I_{it-1}$ and its change in technological knowledge as $\Delta T_{it} = T_{it} - T_{it-1}$, where i and t denote the firms and years in our sample, respectively. Finally, we add an error term to each equation. Piecing these elements together permits us to estimate a model of the form:

$$\Delta I_{it} = \beta_0 \cdot \mathbf{C}_{it-1} + F_{Ii} + Y_{It} + \beta_1 I_{it-1} + \beta_2 T_{it-1} + \varepsilon_{Iit} \tag{6}$$

$$\Delta T_{it} = \beta_3 \cdot \mathbf{C}_{it-1} + F_{Ti} + Y_{Tt} + \beta_4 T_{it-1} + \beta_5 I_{it-1} + \varepsilon_{Tit} \tag{7}$$

where the β, F, and Y are the estimated coefficients of the model.

Overall, based on Equations (2) and (3), we exepect that the impact of the lagged value of each dependent variable on itself will be negative, and that its effect on the other dependent variable will be positive. We turn next to empirically test equations (6) and (7).

4. DATA AND METHODS

We test our model by estimating the econometric equations on panel data for Japanese firms. Our sample is derived from the firms and their foreign subsidiaries listed in annual editions of Toyo Keizai's compendium of Japanese FDI, called *Kaigai Shinshutsu Kigyou Souran* (Japanese Overseas Investments). We used each annual edition from 1990 to 2009 to construct annual technological development and international expansion profiles for our sample firms. This period is relevant for a study of Japanese firms' international expansions, as it was characterized by rapid international growth (UNCTAD, 2009).

We derived annual observations on firm-specific measures from the *NEEDS* tapes and from annual editions of the fourth quarter issues of the *Japan Company Handbook*. Taken together, these data are among the most comprehensive in terms of foreign subsidiary information, with coverage greater than that of the Harvard Multinational Enterprise Project (Beamish, Delios & Lecraw, 1997). These data have been widely used in the literature on international expansion (Goerzen, 2007; Lu *et al.*, 2004; Goerzen, Asmussen, & Nielsen, 2013). Given the dynamic nature of our model, we specifically targeted firms for which we could obtain sufficient data covering long time spans. As a result, our final sample comprised 664 firms operating from 1990 to 2009 in a wide range of two-digit Standard Industrial Code (SIC) manufacturing industries.

4.1 Measures

We measure *international scope* using an inverse Herfindahl score of the dispersion of the number of employees across three main areas – Japan (the home country), Asia Pacific-ex Japan (the home region) and rest of the world. Hence, if u_i is the share of a firm's employees in foreign subsidiaries located in area *i*, then the international scope level is measured as $1 - \sum_{i=1}^{3} u_i \ln(1/u_i)$. This approach is consistent with accepted views that these three areas represent important differences across foreign firm operations (Rugman & Verbeke, 2004; Asmussen, 2009). We performed a logarithmic transformation in the Herfindahl measure to reduce its skewness. International scope was computed based on information obtained from annual editions of the *Japan Company Handbook*, *Japanese Overseas Investments*, and the WorldScope database. Consistent with the extant literature (Bloodgood, Sapienza & Almeida, 1996; Goerzen & Beamish, 2003; Hashai, 2011), we believe that employment data is a straightforward quantitative measure for the international footprint of firms. The change in the above measure is defined as the difference between its level in two adjacent years.

We measure technological knowledge as the number of successful patent applications in the five years prior to an observation. Our five-year window to measure knowledge stocks follows Katila and Ahuja (2002), Wu and Stanley (2009), and others. This measure is consistent with our definition of technological knowledge as it is relative to the current technological frontier. Since this frontier advances over time, a patent in 1980 does not represent the same absolute level of technological knowledge as a patent in 1995, but both of them can be considered a relative advance over the current technological frontier at that time. These data were obtained from the United States Patent and Trademark Office (USPTO), where Japanese firms often apply for patents (Belderbos, 2001; Iwasa & Odagiri, 2004; Penner-Hahn & Shaver, 2005). Collectively, our sample's firms successfully applied for 341,500 patents in this period. We performed a logarithmic transformation in this measure to reduce its skewness. The change in technological knowledge is defined as the difference between the technological knowledge of a given firm in two adjacent years.

Control variables. Our models have firm level control variables, which were derived from the *NEEDS* tapes. Consistent with the literataure we use the number of *employees* as our measure of firm size (Bloodgood, Sapienza & Almeida, 1996; Goerzen & Beamish, 2003; Hashai, 2011). A positive relationship is expected between a firm's size and its changes in technological knowledge and international scope (Chandler, Hikino & Chandler, 2009). Next, we control for two performance measures to account for possible performance effects on changes in technological knowledge and international scope. *Return on sales* is the ratio of each firm's profits before tax to sales. *Return on assets* is the ratio of each firm's profits before tax to fixed and current assets. We control for *advertising intensity*, which is the ratio of advertising expenses to sales, which measures the influences of firm-specific marketing resources on changes in technological knowledge and international scope (Delios & Beamish, 1999). We control for the effect of each firm's *Tangible assets*, as measured as the monetary value (millions of JPY) of each firm's tangible fixed assets. We expect tangible assets to be positively correlated with technological and international growth. Finally, we include fixed effects for time and industry (2 digit SIC).

4.2 Empirical Estimation

We estimate two regression models where the changes in each dimension are the dependent variables, as shown in Equations (6) and (7). Our estimation approach addresses the risk that some of our independent variables or control variables may be subject to endogeneity. A simultaneity bias may occur when both independent and dependent variables are influenced by a third unobserved variable. A failure to control for a common determinant can lead to the estimation of a spurious relationship between focal variables. The firms in our sample vary systematically in their levels of and changes in focal variables due to the influence of unobservable, firm-specific characteristics, such as managerial skills or other unmeasured capabilities. These influences, in turn, would lead to spuriously significant coefficients on our estimates if we applied ordinary least squares (OLS) regressions to estimate the changes in technological knowledge and international scope. For example, suppose there are omitted variables that affect a firm's ability to expand internationally and its ability to acquire new technological knowledge. In that case, the correlation between these dimensions would be inflated, and we would risk estimating a significant effect—international scope affecting technological knowledge and vice versa—even if no such effect existed.

As the regression models require control for several endogenous variables simultaneously, we used the Arellano and Bond (AB) panel data system generalized method of moments (GMM) (Arellano & Bond, 1991; Arellano & Bover, 1995), which is suitable for models with delta as a dependent variable (Roodman, 2009). This approach uses internal instruments generated by first-differencing multiple lags of the regressors. It allows us to overcome endogeneity and control for unobserved firm-specific heterogeneity, in the presence of heteroskedasticity and arbitrary patterns of autocorrelation within firms (Greene, 2008).

We ran Wald tests to justify the inclusion of industry dummies and year fixed. The rejection of the respective null hypothesis justified the inclusion of industry dummies and year fixed effects. The fixed effects for time help to remove universal time-related shocks from the error terms and prevent cross-individual correlation for system GMM regressions (Roodman, 2009). These tests imply that the estimated trajectories are industry-specific and time-specific. To ensure multicollinearity did not bias estimations, we ran tests that showed the maximum variance inflation factor to be less than ten (Kleinbaum, Lawrence, Muller & Nizam, 1998). We tested for autocorrelation via the Sargan test of over-identifying restrictions. All models are well-fitted, as the probability of the Wald chi-squared was less than 0.001.

5. RESULTS

Descriptive statistics and correlations are in Table 1. The firms have an average inverse international scope Herfindahl measure of 0.56 and a measure of technological knowledge (average number of five year patent counts) of 161. The firms average Japanese Yen 470 Billion in sales and 3,750 employees.

*** Table 1 about here ***

Table 2 presents the estimated coefficients of the changes in technological knowledge and international scope. We present results with and without inclusion of control variables. The two sets of results are consistent. The results confirm our expectations regarding the direction of the effects, based on Equations (2) and (3). The negative impact of the lagged value of each dependent variable on itself supports the model's predictions regarding saturation in international scope as well as decreasing technological knowledge enhancement. The positive impact of the level of international scope on the change in technological knowledge is consistent with the model's predictions. The effect in the other direction is also supported. Control variables are signed as expected. The Sargan tests (Blundell *et al.*, 1998) confirm the validity of the instruments. The null hypothesis of no serial autocorrelation of the residuals is not rejected, suggesting that autocorrelation is not an issue.

*** Table 2 about here ***

The coefficient estimates allow us to estimate empirical growth trajectories. We consider first the models without control variables, as they allow for a clean estimate without confounding by firm-specific changes. The estimates reported in the two left-hand columns in Table 2 tell us the predicted rate of change in both *I* and *T* as a function of the current states of these variables for the firms in our sample. Since the model includes fixed industry and year effects, the constant reported in the table captures the value of the reference industry (food products) in the reference year (1990). To obtain an average over all industries and all years, we can average the fixed effects for industry and year, and add the result to the constant in each equation. By doing this, Equations (6) and (7) are found to be:

$$\Delta I_t = 0.268 - 0.373 I_t + 0.010 T_t \tag{8}$$

$$\Delta T_t = 0.059 - 0.026 T_t + 0.035 I_t \tag{9}$$

These are empirical estimates of the coefficients in Equations (2) and (3) for the average firm in the average industry and average year. This means we can derive from these estimates a stream plot with dynamic steady states, similar to Figure 1. Setting the predicted changes in these two equations equal to zero and solving for the steady states gives us the empirical counterparts to Equations (4) and (5):

$$\Delta I_t = 0 \iff I_t = 0.718 + 0.094 T_t \tag{10}$$

$$\Delta T_t = 0 \iff T_t = 2.269 + 0.385 I_t \tag{11}$$

These two equations can be solved for a steady state of $I = 0.966$ and $T = 2.641$. Figure 4 shows these steady states and the stream plots associated with them, and plots the sample average of *I* and *T*. The sample mean as shown in the figure marks that sample firms are on average found in the virtuous cycle area. However, they are relatively close to the steady state of *I*, while having substantial room for growth before they reach the steady state of *T*.

*** Figure 4 About Here ***

It is important to stress that the sample average indicated in the figure is exactly that—an average, which conceals a great deal of heterogeneity. As such, Figure 4 does *not* imply that all firms are always in the virtuous cycle area. In fact, our sample includes firms belonging to all four trajectories, including global explorers, domestic exploiters, and overstretchers, in different industries at different points in time.

5.1 Robustness tests

We ran several models to test robustness. First, we ran a standard fixed effects model, which yields results consistent with our Arrelano-Bond specification. Second, since our theory predicts that the changes in international scope and technological knowledge are determined simultensouly, we also ran dynamic structural equation models (SEM) for the two measures. Dynamic SEM models allow us to control for unobserved confounds and for lagged, reciprocal causation by using maximum likelihood (ML) estimation as implemented in structural equation modeling (Allisson, Williams and Moral-Benito, 2017). While the Arrelano-Bond GMM models used in our main analyses have the advantage of controlling for potential endogeneity, Dynamic SEM models have the advantage of simultaneously determining both dependent variables. Table 3 includes the results of the Dynamic SEM models. Reassuringly, Table 3 reveals the same patterns found in Tables 2.

*** Table 3 About Here ***

We tested alternative measures for international scope and technological knowledge. We measured international scope using the number of employees in foreign subsidiaries. Technological knowledge was operationalized as the number of patents for a firm over five years that have been applied by a firm's inventors residing outside of Japan, reflecting each firm's foreign knowledge stock. We used another measure for technological scope, which was an inverse herfindhal measure of the dispersion of inventors across three areas – Japan, Asia Pacific and the rest of the world. The results derived from running the same models with alternative measures are consistent with our main regressions, corroborating our main model. Adding firm sales and liabilities to our regression models did not change the results and neither did adding curvilinear effects on the lags of international scope and technological knowledge.

We further used fixed effects coefficients in our regressions to derive separate equations for each industry (while still averaging the year fixed effects). Each industry has a unique intercept, leading to an industry-specific steady state.[4] The relative steady states of these industries in our sample matches intuition and casual observation as it indicates that the potential for international and technological scope is greater in some industries than in others and that, on average, firms in different industries belong to different trajectories. For instance, firms in the Electronics and Communication indsutries belong on average to the virtous cycle trajectory. Firms in the Pipline industry belong to the domestic exploiter trajectory. Firms in the Paper and Chemicals industries belong to the global explorer trajectory, while firms in the Furniture industry belong to the overstreching trajectory. Based on the year fixed effects, furthermore, we can see that the steady states move slightly over the years, with a dip after the financial crisis. Taken together these analyses lend support to the empirical validity of the four trajectories that our theoretical model predicts.

6. DISCUSSION

Our research was developed with the objective of conceptualizing, modeling and depicting the coevolutionary development trajectories of international scope and technological knowledge, for a large group of firms over a long period of time. To achieve this objective, we reviewed and integrated key observations from several streams of research connected to the fundamental idea that technology and international growth are critical concepts in our understanding of the global strategy of firms.

[4] These additional post-hoc analyses are available from the authors upon request.

The conceptual foundation of our approach is coevolution. A coevolutionary approach emphasizes reciprocities in the growth paths of different areas in a firm, which in our case are international scope and technological knowledge. By casting the process as coevolutionary, we are able to depart from prior notions of independent influences of international scope and technological knowledge on each other. Instead, we show how both international scope and technological knowledge jointly expand and retract, but with independence from each other, as their development is driven by the fundamental objective of performance maximization.

By building from tenets about the antecedents to international expansion and to technological knowledge growth, while placing these under a coevolutionary lens, we are able to develop a formal model that illustrates how firms expand and retract at a corporate level simultaneously along both dimensions. The implementation of our dynamic optimization model yields insight into multi-decade trajectories of the international scope and technological knowledge changes of MNCs.

Our modeling reveals complex non-linear trajectories where diminishing returns to continued expansion at high levels of international scope or technological knowledge lead to a substitution between the two. Importantly, the model adopts a dynamic perspective on the growth of a firm's international scope and its technological knowledge. We view this growth as the outcome of interdependent strategic decisions of far-sighted managers seeking to maximize and MNC's performance.

As we have mentioned, we were concurrently motivated by research on international divestment and technological retreat. As such, we highlight within our model that international growth and technological advancement are not unidirectional and irreversible. Instead, we show empirically that firms go through periods of retraction in international scope (Bermini, et al., 2016;

Kafouros, et al., 2021) and decay in technological knowledge (Berman, et al., 2002; Darr, et al., 1995; Goto & Suzuki, 1989). Not only do we depict this in our model and data, but our literature integration as guided by the conceptual foundation of our model, offers explanations as to why this occurs. These explanations are grounded in our articulation of the resource, organizational and management challenges to corporate growth in the two dimensions.

An important departure of our work is that we do not try to address the question of whether technological knowledge acquisition leads to expansion of international scope, or vice-versa. Instead, we treat this agnostically, accepting possibilities of both leading to changes in the other, or in itself. As such, our model provides a useful tool by which to forge a consideration of the joint paths, modeling the coevolution of the trajectories of international scope and technological knowledge. One of our contributions emerges from this facet of our research design, which enables us to illustrate trajectories of development via the model and then substantiate the model's predictions in the use of empirical data.

Notably, a central attribute of our model is that we can identify four growth trajectories. We label these trajectories as virtuous cycle, global explorer, domestic exploiter and overstretching. Firms belonging to the virtuous cycle trajectory increase their levels of technological knowledge and international scope simultaneously and interdependently up to a steady state from which further expansion is not profitable. The Japanese diversified chemicals, materials plastics and construction company, *Kureha*, is an example of such growth. The company was founded in 1944 as an industrial chemicals and chemical fertilizer company. As it grew into new product areas, it built plants in Japan. Eventually it expanded into the United Kingdom, the Netherlands, China, the USA and Vietnam, among other countries. At the same time, it expanded its technical capabilities to support its growth into new product areas.

Meanwhile, another Japanese chemicals company, *Kuraray*, illustrates growth beyond the equilibrium, in the overstretching trajectory. This company was founded in 1926. It has remained focused as a specialty chemical company but sought to increase its international presence through organic growth and acquisitions. There was an initial expansion of international scope, but a maintenance of the same level of technology (1990-1994). Next, from 1995 to 2003, the company overstretched as it increaseed both its technological knowledge and its international scope. Accordingly, it retreated along both dimensions in the 2004-2008 period to move back towards the theoretical equilibrium. These two cases show that the paths we model and identify empirically exist at the firm-level. Firms belonging to the overstretching trajectory exist beyond *Kuraray*. Another example is *Takara Holdings*, which reduced both its international scope and technological knowledge in the 1990-1994 period, before expanding its international scope (1995-2001), and then later its technological knowledge. This trajectory occurs when the two dimensions are unable to support the continued profitable expansion of each other.

We also observe firms in the the domestic exploiter trajectory. These firms are technologically rich but domestically oriented. They need to reduce their technological expansion and increase their international scope to enter the virtuous cycle. *Tejin* is one such Japanese firm. Between 2001 and 2009, it increased its international scope slowly, while reducing its technological knowledge. Meanwhile, firms in the global explorer trajectory need to reduce their international scope and increase their level of technological knowledge before they can profitably increase both their technological knowledge and international scope. An example is another diversified chemicals Japanese company, *Showa Denko*, which from 1990 to 2009 slowly reduced its international scope, while focusing on substantially growing its technological knowledge.

These examples validate the contemporary relevance of our model. We also see validation for our model in how the various growth trajectories align with extant work on multinational firms. For example, the virtuous cycle trajectory corresponds to firms that rapidly internationalize and increase their technological knowledge as captured in the literature and emphasized in Golovko and Valentini (2011) who studied firms with levels of international scope and technology that were low relative to their steady state. However, in our overarching model, this outcome is only one among several possibilities. Similarly, the domestic exploiter trajectory represents the stereotypical international growth process for firms that possess a technological advantage at home which motivates them to expand internationally (Buckley & Casson, 1976; Caves, 2007). Consistent with the ideas in internalization theory literature, firms with the strongest technologies internationalize the fastest.

We further find that firms that follow the global explorer trajectory correspond to emerging market multinationals, which do not possess technological advantages when entering foreign markets, but do develop such after foreign market entry, often aggressively by acquisitions (Duysters *et al.*, 2009; Luo *et al.*, 2007; Mathews & Cho, 1999; Mathews, 2006). Finally, firms that follow the overstretching trajectory correspond to the phenomenon of 'overambitious international growth' which may hamper performance and hence require them to reduce their international scope through divestment, as in Berry (2010).

In terms of the mechanisms for these effects, our model is predicated on a firm's managers developing strategy that aim to maximize firm performance in the long run, which then leads to our four patterns for the growth of international scope and technological knowledge. Our model emphasizes the important role of the adjustment costs, many of which are related to top management bottlenecks (Dierickx & Cool, 1989; Penrose, 1959) that restrain the extent to which, and the pace at which, firms can expand.

Moreover, our model emphasizes the interdependence between the different strategic expansion moves, which in our case are international and technological expansion, that firms make. We hence highlight the need for coordination among functional managers, such as those responsible for R&D and global marketing. In a broad sense, we see our analysis as a step towards an explicit incorporation of dynamic optimization considerations into the core decisions – product line growth, geographic market growth, technological knowledge growth, among others – found in innovation and management theory.

Elaborating from this point, leads us to consider novel approaches to depict growth dynamics more generally. Our model illustrates that growth in any one dimension of a firm is part of several decisions connected to a far-sighted, long term performance enhancing process. This approach can readily be applied to studies in other areas of management, such as the development of capabilities and market activity (Levinthal & Myatt, 1994); the development of learning and routines (Nelson & Winter, 1982); the development of knowledge, capabilities and a firm's product offerings (Helfat & Raubitschek, 2000); and growth via international and product diversification (Hashai & Delios, 2012; Kumar, 2009). Future work can build on our approach to analyze simultaneous trajectories of growth across a range of strategic moves.

REFERENCES

Abel AB. 1983. Optimal Investment under Uncertainty. *American Economic Review*73(1): 228-233.

Aghion P, Harris C, Howitt P, & Vickers J. 2001. Competition, imitation and growth with step-by-step innovation. *Review of Economic Studies* 68(3): 467-492.

Allison, P.D., Williams, R. & Moral-Benito. E. 2017. Maximum Likelihood for cross-lagged panel models with fixed effects. *Socius*: 3: 1-17.

Almeida P. 1996. Knowledge sourcing by foreign multinationals: Patent citation analysis in the US semiconductor industry. *Strategic Management Journal* 17: 155-165.

Arellano M, & Bond S. 1991. Some tests of specification for panel data - monte-carlo evidence and an application to employment equations. *Review of Economic Studies* 58(2): 277-297.

Arellano M, & Bover O. 1995. Another look at the instrumental variable estimation of error-components models. *Journal of Econometrics* 68(1): 29-51.

Argote L, & Ingram P. 2000. Knowledge transfer: A basis for competitive advantage in firms. *Organizational Behavior and Human Decision Processes* 82(1): 150-169.

Asmussen CG. 2009. Local, regional, or global? Quantifying MNE geographic scope. *Jounral of Internationa Business Studies* 40(7): 1192-1205.

Asmussen CG, Pedersen T, & Dhanaraj C. 2009. Host-country environment and subsidiary competence: Extending the diamond network model. *Jounral of International Business Studies* 40(1): 42-57.

Barkema HG, & Schijven M. 2008. Toward unlocking the full potential of acquisitions: the role of organizational restructuring. *Academy of Management Journal* 51(4): 696-722.

Bartlett CA, & Ghoshal S. 1999. Managing across borders: The transnational solution. *American Foreign Policy Interests* 21(3).

Beamish PW, Delios A, & Lecraw DJ. 1997. *Japanese multinationals in the global economy*. Edward Elgar Cheltenham.

Belderbos R. 2001. Overseas innovations by Japanese firms: an analysis of patent and subsidiary data. *Reserach Policy* 30(2): 313-332.

Benito GRG, & Welch LS. 1997. De-internationalization. *MIR: Management International Review* 37: 7-25.

Benito GRG. 2005. Divestment and international business strategy. *Journal of Economic Geography*, 5(2): 235–251.

Berman SL, Down J, & Hill CWL. 2002. Tacit knowledge as a source of competitive advantage in the National Basketball Association. *Academy of Management Journal* 45(1): 13-31.

Bermini, M. Du J, & Love, JH. 2016. Explaining intermittent exporting: Exit and conditional re-entry in export markets. *Jounral of International Business Studies* 47(9): 1058-1076.

Berry H. 2010. Why do firms divest?. *Organization Science* 21(2): 380-396.

Berry H. 2013. When do firms divest?. *Organization Science* 24(1): 246-261.

Berry H, & Sakakibara M. 2008. Resource accumulation and overseas expansion by Japanese multinationals. *Journal of Economic Behavior & Organization* 65(2): 277-302.

Besanko, D, Dranove, D, Shanley, & M, Schaefer, S. 2010. *The Economics of Strategy*. 6th edition, John Wiley & Sons, Hoboken, NJ.

Bettis RA, & Hitt MA. 1995. The new competitive landscape. *Strategic Management Journal* 16(S1): 7-19.

Birkinshaw, J, Hood, N. , & Jonsson, S. 1998. Building firm‐specific advantages in multinational corporations: the role of subsidiary initiative. *Strategic Management Journal* 19(3): 221-242.

Bloodgood, JM, Sapienza, HJ, & Almeida, JG. 1996. The Internationalization of New High-Potential U.S. Ventures: Antecedents and Outcomes. *Entrepreneurship Theory and Practice* 20(4)): 61-76.

Blundell R, & Bonds S. 1998. Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics* 87(1): 115-143.

Buckley PJ, & Casson M. 1976. *The future of the multinational enterprise*. Macmillan London.

Campa J, & Guillén MF. 1999. The internalization of exports: Firm-and location-specific factors in a middle-income country. *Management Science* 45(11): 1463-1478.

Cantwell J. 1995. The globalization of technology - what remains of the product cycle model. *Cambridge Journal of Economics* 19(1): 155-174.

Cantwell, J., Dunning, J. H., & Lundan, S. M. 2010. An evolutionary approach to understanding international business activity: The co-evolution of MNEs and the institutional environment. *Journal of International Business Studies*, 41(4): 567-586.

Caves RE. 2007. *Multinational Enterprise and Economic Analysis*. Cambridge University Press: Cambridge, UK.

Chiang AC. 1992. *Elements of Dynamic Optimization*. McGraw-Hill: New York.

Chandler AD, Hikino T, & Chandler AD. 2009. *Scale and scope: The dynamics of industrial capitalism*. Harvard University Press.

Cohen WM, & Levinthal DA. 1990. Absorptive capacity - a new perspective on learning and innovation. *Adminstrative Science Quarterly* 35(1): 128-152.

Contractor FJ, Kundu SK, & Hsu C-C. 2003. A three-stage theory of international expansion: The link between multinationality and performance in the service sector. *Jounral of International Business Studies* 34(1): 5-18.

Darr ED, Argote L, & Epple D. 1995. The acquisition, transfer, and depreciation of knowledge in service organizations: Productivity in franchises. *Management Science* 41(11): 1750-1762.

Delios A, & Beamish PW. 1999. Geographic scope, product diversification, and the corporate performance of Japanese firms. *Strategic Management Journal* 20(8): 711-727.

Delios A, & Henisz WJ. 2003. Political hazards, experience, and sequential entry strategies: the international expansion of Japanese firms, 1980–1998. *Strategic Management Journal* 24(11): 1153-1164.

Dierickx I, & Cool K. 1989. Asset stock accumulation and sustainability of competitive advantage. *Management Science* 35(12): 1504-1511.

Ding M, Ross WT, & Rao VR. 2010. Price as an indicator of quality: implications for utility and demand functions. *Journal of Retailing* 86(1): 69-84.

Dorfman R. 1969. An economic interpretation of optimal control theory. *The American Economic Review* 59: 817-831.

Duhaime, IM, & Grant, JH. 1984. Factors influencing divestment decision‐making: Evidence from a field study. *Strategic Management Journal* 5(4): 301-318.

Dunning JH. 1996. *The geographical sources of the competitiveness of firms: some results of a new survey*. University of Reading, Department of Economics.

Dunning JH, & Rugman AM. 1985. The influence of hymer dissertation on the theory of foreign direct-investment. *The American Economic Review* 75(2): 228-232.

Dunning JH, Lundan, SM. 2008. *Multinational Enterpises and the Global Economy*. Edward Elgar, Cheltenham, UK.

Duysters G, Jacob J, Lemmens C, & Yu JT. 2009. Internationalization and technological catching up of emerging multinationals: a comparative case study of Chinas Haier group. *Industrial and Corporate Change* 18(2): 325-349.

Eden L, & Miller SR. 2004. Distance matters: Liability of foreignness, institutional distance and ownership strategy. *Advances in Internatational Management* 16:187-221.

Fujita, M, Krugman, P, & Venables, AJ. 2001. *The Spatial Economy: Cities, Regions, and International Trade*.MIT Press, Cambridge, MA.

Gassmann, O., & Keupp, MM. 2007. The competitive advantage of early and rapidly internationalizing SMEs in the biotechnology industry: A knowledge-based view. *Journal of World Business*, 42: 350–366.

Goerzen A. 2007. Alliance networks and firm performance: the impact of repeated partnerships. *Strategic Management Journal* 28(5): 487-509.

Goerzen, A., & Beamish, P. 2003. Geographic scope and multinational enterprise performance. *Strategic Management Journal*, 24(13): 1289-1306.

Goerzen, A., Asmussen, C. & Nielsen, B. 2013. Global cities and multinational enterprise location strategy. *Journal of International Business Studies* 44: 427–450.

Golovko E, & Valentini G. 2011. Exploring the complementarity between innovation and export for SMEs' growth. *Jounral of International Business Studies* 42(3): 362-380.

Goto, A. & Suzuki, K. 1989. R & D capital, rate of return on R & D investment and spillover of R & D in Japanese manufacturing industries. *Review of Economics and Statistics,* 71(4): 555-564.

Gould JP. 1968. Adjustment costs in the theory of investment of the firm. *The Review of Economic Studies* 35: 47-55.

Grant RM. 1996. Toward a knowledge-based theory of the firm. *Strategic Management Journal* 17: 109-122.

Greene, W.H. 2008. *Econometric Analysis*. Upper Saddle River, New Jersey: Pearson Prentice Hall.

Hashai N. 2011. Sequencing the expansion of geographic scope and foreign operations by "born global" firms. *Jounral of International Business Studies* 42(8): 995-1015.

Hashai N, & Delios A. 2012. Balancing growth across geographic diversification and product diversification: A contingency approach. *International Business Review* 21(6): 1052-1064.

Helfat CE, & Raubitschek RS. 2000. Product sequencing: Co-evolution of knowledge, capabilities and products. *Strategic Management Journal* 21(10-11): 961-979.

Hennart J-F. 2007. The theoretical rationale for a multinationality-performance relationship. *Management International Review* 47(3): 423-452.

Hitt Ma, Hoskisson RE, & Kim H. 1997. International diversification: effects on innovation and firm performance in product-diversified firms. *Academy of Management Journal* 40(4): 767-798.

Hymer S. 1976. *The international operations of national firms: A study of direct foreign investment*. MIT press Cambridge, MA.

Iwasa T, & Odagiri H. 2004. Overseas R&D, knowledge sourcing, and patenting: an empirical study of Japanese R&D investment in the US. *Research Policy* 33(5): 807-828.

Jaffe AB, Trajtenberg M, & Henderson R. 1993. Geographic localization of knowledge spillovers as evidenced by patent citations. *Quarterly Journal of Economics* 108(3): 577-598.

Johanson J, & Vahlne J-E. 1977. The internationalization process of the firm-a model of knowledge development and increasing foreign market commitments. *Jounral of International Business Studies* 8: 23-32.

Jones GR, & Hill CWL. 1988. Transaction cost analysis of strategy-structure choice. *Strategic Management Journal* 9(2): 159-172.

Kafouros, M. Cavusgil, S.T., Devinney T.M., Ganotakis P., Fainshmidt, S. 2021. Cycles of de-internationalization and re-internationalization: Towards an integrative framework, *Journal of World Business* (forthcoming).

Katila R, & Ahuja G. 2002. Something old, something new: a longitudinal study of search behavior and new product introduction. *Academy of Management Journal* 45(6): 1183-1194.

Kim WC, Hwang P, & Burgers WP. 1993. Multinationals' diversification and the risk‐return trade‐off. *Strategic Management Journal* 14(4): 275-286.

Kleinbaum, D.G., Lawrence, L.K., Muller, K.E., & Nizam, A. 1998. *Applied regression analysis and other multivariable methods* (3rd edition). Pacific Grove, CA: Brooks/Cole.

Klepper S. 1996. Entry, exit, growth, and innovation over the product life cycle. *The American Economic Review* 86(3): 562-583.

Knott AM, Bryce DJ, & Posen HE. 2003. On the strategic accumulation of intangible assets. *Organization Science* 14(2): 192-207.

Kumar MVS. 2009. The relationship between product and international diversification: the effects of short-run constraints and endogeneity. *Strategic Management Journal* 30(1): 99-116.

Laamanen T, & Keil T. 2008. Performance of serial acquirers: toward an acquisition program perspective. *Strategic Management Journal* 29(6): 663-672.

Lehrer, M., & Asakawa, K. 2002. Offshore knowledge incubation: The ''third path'' for embedding R&D labs in foreign systems of innovation. *Journal of World Business*, 37(4): 297–306.

Levinthal D, & Myatt J. 1994. Coevolution of capabilities and industry - the evolution of mutual fund processing. *Strategic Management Journal* 15: 45-62.

Liu X, & Buck T. 2007. Innovation performance and channels for international technology spillovers: Evidence from Chinese high-tech industries. *Research Policy* 36(3): 355-366.

Liu, X., & Zou, H. 2008. The impact of greenfield FDI and mergers and acquisitions on innovation in Chinese high-tech industries. *Journal of World Business*, 43: 352–364.

Lu JW, & Beamish PW. 2004. International diversification and firm performance: the s-curve hypothesis. *Academy of Management Journal* 47(4): 598-609.

Lucas RE. 1967. Adjustment costs and the theory of supply. *The Journal of Political Econom*y 75: 321-334.

Luo YD, & Tung RL. 2007. International expansion of emerging market enterprises: a springboard perspective. *Jounral of International Business Studies* 38(4): 481-498.

Mahoney JT, & Pandian JR. 1992. The resource-based view within the conversation of strategic management. *Strategic Management Journal* 13(5): 363-380.

March, J.G. 1991 Exploration and exploitation in organisational learning. *Organization Science*, 2(1): 71-87.

Markides, CC. 1992. Consequences Of Corporate Refocusing: Ex Ante Evidence. *Academy of Management Journal* 35(2): 398-412.

Martin X, & Salomon, R. 2003. Tacitness, Learning, and International Expansion: A Study of Foreign Direct Investment in a Knowledge-Intensive Industry. *Organization Science* 14(3): 297-311.

Mathews, JA, & Cho, DS. 1999. Combinative capabilities and organizational learning in latecomer firms: The case of the Korean semiconductor industry. *Journal of World Business*, 33(4): 139-156.

Mathews JA. 2006. Dragon multinationals: New players in 21st century globalization. *Asia Pacific Journal of Management* 23(1): 5-27.

Michailova, S, & Mustaffa, Z. 2012. Subsidiary knowledge flow in multinational corporations: Research accomplishments, gaps, and opportunities. *Journal of World Business*, 47: 383–396.

McEvily SK, & Chakravarthy B. 2002. The persistence of knowledge-based advantage: An empirical test for product performance and technological knowledge. *Strategic Management Journal* 23(4): 285-305.

Miller DJ, Fern MJ, & Cardinal LB. 2007. The use of knowledge for technological innovation within diversified firms. *Academy of Management Journal* 50(2): 308-326.

Moliterno, TP, & Wiersema, MF. 2007. Firm performance, rent appropriation, and the strategic resource divestment capability, *Strategic Management Journal*, 28(11), 1065-1087.

Morck R, & Yeung B. 1991. Why investors value multinationality. *Journal of Business* 64(2): 165-187.

Morck R, & Yeung B. 1997. *Why investors sometimes value size and diversification: the internalization theory on synergy*. Rearch seminar paper, Mitsui Life Financial Research Center, School of Business Administration, University of Michigan.

Nachum L, & Zaheer S. 2005. The persistence of distance? The impact of technology on MNE motivations for foreign investment. *Strategic Management Journal* 26(8): 747-767.

Nelson RR, & Winter SG. 1982. *An evolutionary theory of economic change*. Harvard University Press: Cambridge, MA.

Patel, P, & Pavitt, K. 1997. The technological competencies of the world's largest firms: Complex and path-dependent, but not much variety. *Research Policy* 26(2): 141-156.

Penner-Hahn J, & Shaver JM. 2005. Does international research and development increase patent output? An analysis of Japanese pharmaceutical firms. *Strategic Management Journal* 26(2): 121-140.

Penrose ET. 1959. *The Theory of the Growth of the Firm*. Blackwell: Oxford.

Reed R, & Defillippi RJ. 1990. Causal ambiguity, barriers to imitation, and sustainable competitive advantage. *Academy of Management Review* 15(1): 88-102.

Richter, N.F. 2014. Information costs in international business: Analyzing the effects of economies of scale, cultural diversity and decentralization. *Management International Review,* 54(2):171-193.

Roodman, D. 2009. How to do xtabond2: An introduction to difference and system GMM in Stata. *Stata Journal*, 9(1): 86-136.

Romer PM. 1986. Increasing returns and long-run growth. *Journal of Political Econom*y 94(5): 1002-1037.

Rugman AM. 1981. *Inside The Multinationals: The Economics Of Internal Markets*. Columbia University Press:New York.

Rugman AM, & Verbeke, A. 2004. A perspective on regional and global strategies of multinational enterprises *Jounral of International Business Studies* 35(1): 3-18.

Salomon RM, & Shaver JM. 2005. Learning by exporting: new insights from examining firm innovation. *Journal of Economics & Management Strategy* 14(2): 431-460.

Shone R. 2002. *Economic Dynamics: Phase Diagrams And Their Economic Application*. Cambridge University Press:Cambridge, UK.

Spender JC. 1996. Making knowledge the basis of a dynamic theory of the firm. *Strategic Management Journal* 17: 45-62.

Tallman S, & Li JT. 1996. Effects of international diversity and product diversity on the performance of multinational firms. *Academy of Management Journal* 39(1): 179-196.

Tan D, & Mahoney JT. 2007. The dynamics of Japanese firm growth in US industries: the Penrose effect. *Management International Review* 47(2): 259-279.

Teece DJ. 1986. Profiting from technological innovation - implications for integration, collaboration, licensing and public-policy. *Research Policy* 15(6): 285-305.

Tirole J. 1988. *The theory of industrial organization*. MIT Press: Cambridge, MA.

Tomassen, S., Benito, G.R.G. & Lunnan, R. 2012. Governance costs in foreign direct investments: An MNC headquarters challenge. Journal of International Management, 18(3):233-246.

UNCTAD. 2009. Assessing the impact of the current financial and economic crisis on global FDI flows http://unctad.org/en/docs/diaeia20093_en.pdf [31 October 2014].

Van den Bergh, J. C. J. M., & Stagl, S. 2003. Coevolution of economic behaviour and institutions: towards a theory of institutional change. *Journal of Evolutionary Economics*, 13(3): 289-317.

Vermeulen F, & Barkema H. 2002. Pace, rhythm, and scope: Process dependence in building a profitable multinational corporation. *Strategic Management Journal* 23(7): 637-653.

Von Zedtwitz, M, & Gassmann, O. 2002. Market versus technology drive in R&D international growth: four different patterns of managing research and development. *Research Policy* 31(4): 569-588.

Wu J, & Stanley MT. 2009. Knowledge stock, exploration, and innovation: research on the United States electromedical device industry. *Journal of Business Research* 62(4): 474-483.

Zaheer S. 1995. Overcoming the liability of foreignness. *Academy of Management Journal* 38(2): 341-363.

Zahra SA, Ireland RD, & Hitt MA. 2000. International expansion by new venture firms: international diversity, mode of market entry, technological learning, and performance. *Academy of Management Journal* 43(5): 925-950.

Table 1: **Descriptive statistics and correlations**

Variables	Obs	Mean	Std. Dev.	Min	Max
(1) International scope	10,201	0.56	0.30	0.10	1.00
(2) Technological knowledge (thousands)	10,276	0.161	0.769	0.08	13.24
(3) Employees (thousands)	10,201	3,774	8,636	1	111,000
(4) Sales (Billion JPY)	8,363	0.47	1.39	0.0006	23.10
(5) Return on assets	8,369	0.04	0.06	-0.46	0.51
(6) Return on sales	8,369	0.04	0.13	-8.82	1.15
(7) Advertising intensity	6,358	0.01	0.03	0.000014	0.40
(8) Tangible assets (Billion JPY)	8,363	0.52	1.40	0.0007	19.78

Correlations	1	2	3	4	5	6	7
(1) International scope	1						
(2) Technological knowledge	-0.091	1					
(3) Employees	-0.130	0.481	1				
(4) Sales	-0.067	0.436	0.284	1			
(5) Return on assets	-0.047	0.025	-0.009	-0.009	1		
(6) Return on sales	-0.029	0.015	-0.001	-0.007	0.233	1	
(7) Advertising intensity	-0.113	0.070	0.033	0.036	0.118	0.062	1
(8) Tangible assets	-0.047	0.476	0.243	0.189	-0.007	0.01	0.036

Note: Values above 0.025 are significant at the $p < 0.05$ level.

Table 2: Arellano Bond GMM Regression Models for the Relationships between Changes in International Scope and Technological Knowledge

Dependent variable	Change in international scope	Change in technological knowledge	Change in international scope	Change in technological knowledge
Variables	Without controls		With controls	
International scope	-0.373***		-0.381***	
	(0.029)		(0.031)	
Technological knowledge	0.010***		0.009***	
	(0.003)		(0.003)	
Technological knowledge		-0.026***		-0.016***
		(0.001)		(0.001)
International scope		0.035***		0.018**
		(0.007)		(0.008)
Employees			-0.000	0.002***
			(0.000)	(0.000)
Return on assets			-0.091	0.043
			(0.097)	(0.023)
Return on sales			-0.005	-0.009
			(0.058)	(0.014)
Advertising intensity			-0.544***	-0.007
			(0.154)	(0.037)
Tangible assets			-0.001	-0.001
			(0.003)	(0.001)
Industry	+	+	+	+
Year	+	+	+	+
Constant	0.164**	-0.002	0.099	-0.032
	(0.054)	(0.012)	(0.077)	(0.018)
Observations	7,705	7,709	6,357	6,358
N	844	845	662	663
Sargan Test (Prob>Chi^2)	0.190	0.263	0.184	0.177
2nd order serial correlation (Pr>Z)	0.534	0.503	0.806	0.790
Wald test	309.7	309.5	310.8	372.1

Notes: Standard errors in brackets; *** $p<0.001$, ** $p<0.01$, * $p<0.05$, $^{+}$ $p<0.1$

Table 3: **Dynamic SEM Regression Models for the Relationships between Changes in International Scope and Technological Knowledge**

Dependent variable	Change in international scope	Change in technologica l knowledge
Variables		
International scope	-0.213***	
	(0.007)	
Technological knowledge	0.001^{+}	
	(0.001)	
Log (International scope)		
Log (Technological knoweldge)		
Technological knowledge		-0.024***
		(0.002)
International scope		0.001^{+}
		(0.001)
Log (Technological knowledge)		
Log (International scope)		
Employees	-0.000	0.002***
	(0.000)	(0.000)
Return on assets	-0.122	0.047
	(0.077)	(0.038)
Return on sales	0.041	-0.014
	(0.048)	(0.024)
Advertising intensity	-0.085	0.005
	(0.114)	(0.056)
Tangible assets	-0.000	-0.012**
	(0.008)	(0.004)
Industry	+	+
Year	+	+
Constant	0.164**	-0.002
	(0.054)	(0.002)
Observations	7,450	7,450
N	817	817
Log likelihood	9446.92	9446.92

Notes: Standard errors in parentheses; *** $p<0.001$, ** $p<0.01$, * $p<0.05$, $^{+}$ $p<0.1$

Figure 1: Trajectories of International Scope and Technological Knowledge: From the Dynamic Optimization Model

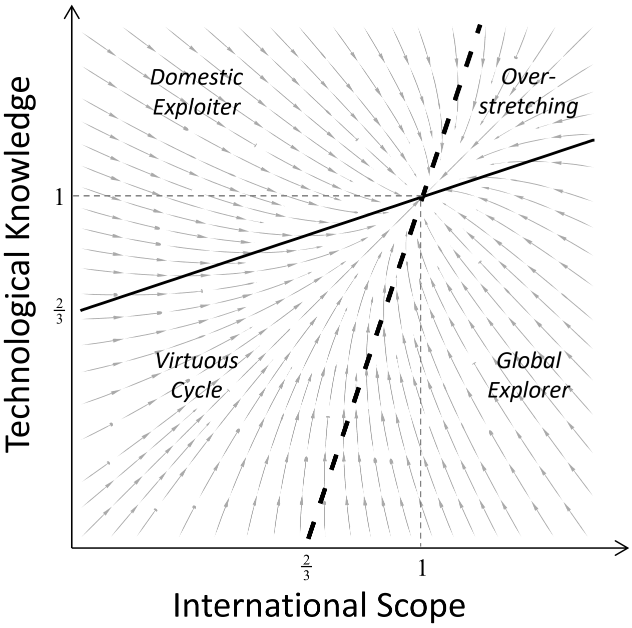
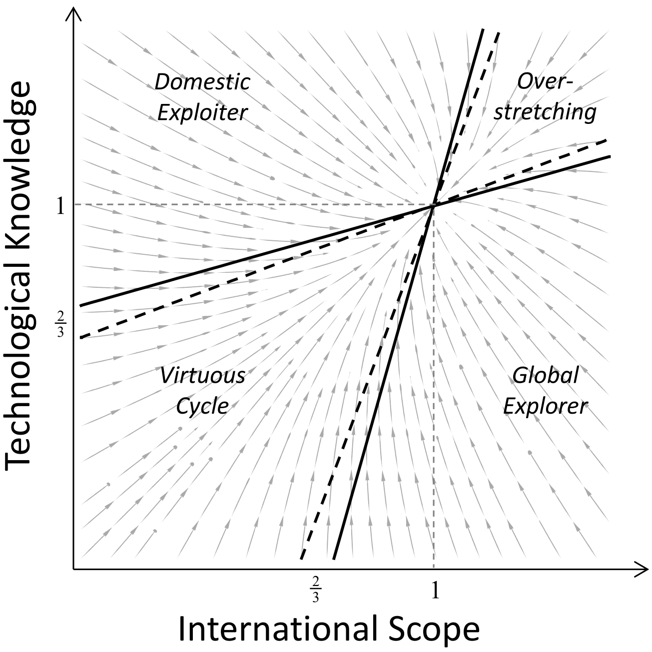


Figure 2: Impact of Extreme Discount Rates on Trajectories



Note: $p = \frac{1}{10}$ (solid lines), $p = \frac{9}{10}$ (dashed lines)

Figure 3: Interdependence between International Scope and Technological Knowledge

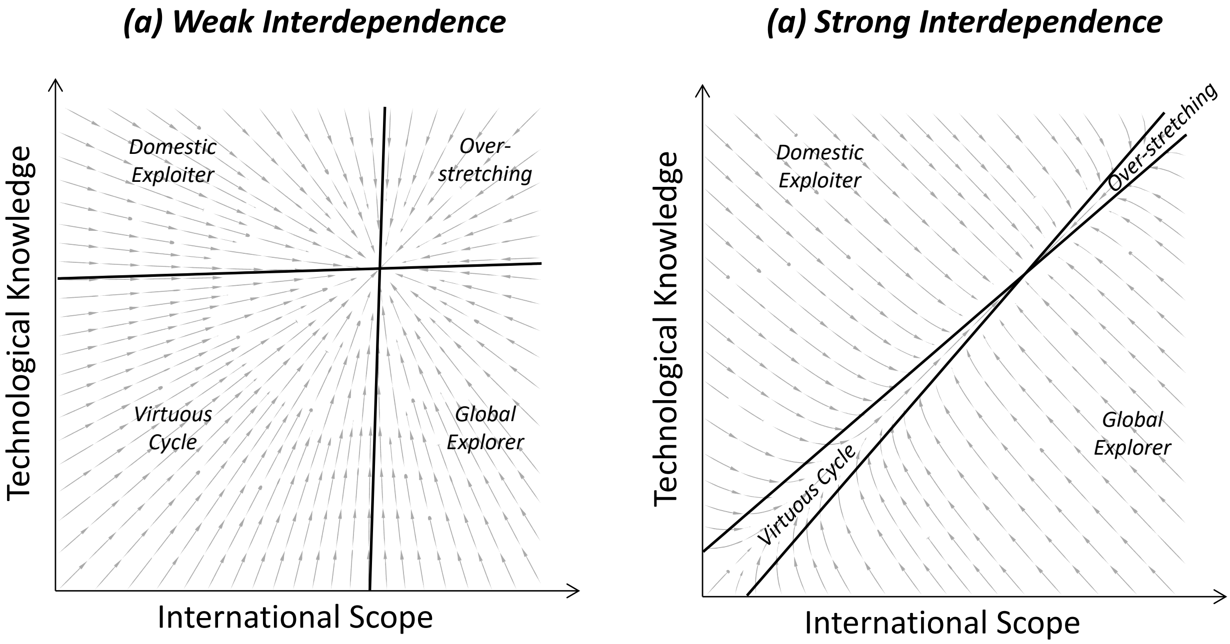
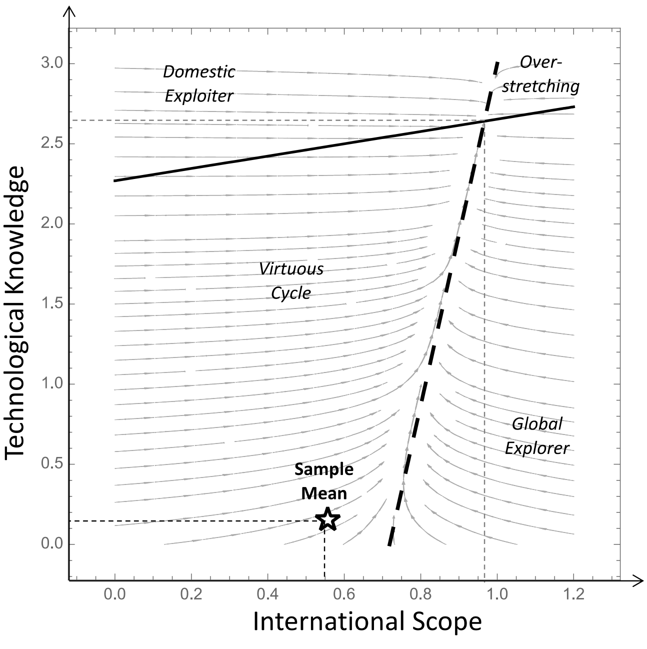


Figure 4: Empirical Trajectories of International Scope and Technological Knowledge: Derived from Coefficient Estimates in Table 2



The Coevolution of International Scope and Technological Knowledge in MNCs

Mathematical Appendix:
Derivation of optimal paths

The objective of the firm is to choose the trajectories of *I* and *T* that maximize the present value of its profit stream as given in Equation (1b). To find these optimal paths, we draw on the calculus of variations, according to which the trajectories that maximize this integral must satisfy two Euler equations (Chiang, 1992):

$$\frac{\partial \tilde{H}}{\partial I}-\frac{d}{dt}\frac{\partial \tilde{H}}{\partial \dot{I}}=e^{-t/2}\left(1-2I_t+T_t-2p\dot{I}_t+2\ddot{I}_t\right)=0 \quad \text{(A1)}$$

$$\frac{\partial \tilde{H}}{\partial T}-\frac{d}{dt}\frac{\partial \tilde{H}}{\partial \dot{T}}=e^{-t/2}\left(1-2T_t+I_t-2p\dot{T}_t+2\ddot{T}_t\right)=0\,, \quad \text{(A2)}$$

where $\ddot{I}_t$ and $\ddot{T}_t$ represent the second time derivative of *I* and *T* respectively and *p* is the discount rate. Each of these equations can be rearranged to provide an intuitive interpretation. For example, Equation (A1) implies that $1-2I_t+T_t-2p\,\dot{I}_t+2\ddot{I}_t=0 \Leftrightarrow 2\dot{I}_t=(1-2I_t+T_t)/p+2\ddot{I}_t/p$. This means that at any point in time *t*, the marginal cost of increasing the instantaneous adjustment rate $(2\dot{I}_t)$ must be equal to the present value of the marginal profit from the resulting increased international scope $(1-2I_t+T_t)/p$ plus the present value of the future adjustment cost savings $2\ddot{I}_t/p$. Hence, no change in the rate of adjustment will increase the overall present value of profits, implying a maximum. The Euler equations constitute a system of two differential equations that can be solved for the two unknown time paths, $I(t)$ and $I(t)$. However, the model is quite complex given that there are adjustment costs in both dimensions and a closed-form solution is therefore not feasible for general discount rate values. As the choice of discount rate only has a very limited impact on the theoretical implications of the model, which (as shown below) are largely the same regardless of whether *p* is close to 0 or 1, we will start by demonstrating the solution for a midpoint between these two extremes, $p=\frac{1}{2}$. Then, in a subsequent analysis, we explore the comparative statics of the discount rate.

As both Equations (A1) and (A2) are second-order differential equations, the general solutions will include four arbitrary constants, but these can be defined by setting two initial states and using two transversality conditions based on the time horizon over which the firm maximizes profits (Chiang, 1992). As to the former, we denote the firm's starting levels of international scope and technological knowledge simply as I_0 and T_0, respectively. As to the latter, there is some controversy as to the use of infinite-horizon transversality conditions and different approaches to solve these types of models have been proposed (Chiang, 1992). The approach we choose here is to break the solution down into two more basic steps, first solving the dynamic optimization problem for an arbitrary time horizon denoted θ, and then examining what the optimal time paths look like as $\theta \rightarrow \infty$. The two transversality conditions are then given by:

$$-2e^{-p\theta}\dot{I}\left(\theta\right)=0 \tag{A3}$$

$$-2e^{-p\theta}\dot{T}\left(\theta\right)=0 \tag{A4}$$

These transversality conditions, in combination with the Euler equations, are in theory sufficient to identify the optimal time paths of the firm. In practice, however, as mentioned in the paper, a closed-form solution is not feasible for general discount rates and we therefore solve the model first for $p=\frac{1}{2}$. Substituting this into the equations above and solving for the optimal time paths results in:

$$I\left(t\right)=\tfrac{1}{2}e^{-t}\left(2e^{t}+I_0-T_0+e^{t/2}\left(I_0+T_0-2\right)+\frac{2\left(-1+e^{5t/2}\right)\left(I_0-T_0\right)}{2+3e^{5\theta/2}}+\frac{\left(-e^{t/2}+e^{2t}\right)\left(I_0+T_0-2\right)}{1+2e^{3\theta/2}}\right) \tag{A5}$$

$$T\left(t\right)=\tfrac{1}{2}e^{-t}\left(2e^{t}+T_0-I_0+e^{t/2}\left(T_0+I_0-2\right)+\frac{2\left(-1+e^{5t/2}\right)\left(T_0-I_0\right)}{2+3e^{5\theta/2}}+\frac{\left(-e^{t/2}+e^{2t}\right)\left(T_0+I_0-2\right)}{1+2e^{3\theta/2}}\right) \tag{A6}$$

The two fractions on the far right in Equations (A5) and (A6) contain the time horizon in the denominator and will therefore approach zero as the firm's time horizon expands. For $\theta \rightarrow \infty$, hence, the optimal time paths of the firm can be reduced to the expressions in Equations (A7) and (A8), below:

$$I\left(t\right)=\tfrac{1}{2}e^{-t}\left(2e^{t}+I_0-T_0+e^{t/2}\left(I_0+T_0-2\right)\right) \tag{A7}$$

$$T\left(t\right)=\tfrac{1}{2}e^{-t}\left(2e^{t}+T_0-I_0+e^{t/2}\left(T_0+I_0-2\right)\right) \tag{A8}$$

To understand these time paths intuitively, it is useful to first look at their initial and asymptotic values. If we substitute $t = 0$ into them, we obtain $I(t) = I_0$ and $T(t) = T_0$, while the limit of the paths for $t \to \infty$ is $I = T = 1$, which is exactly the point we have previously derived as being the optimal position in the absence of adjustment costs. Hence, these expressions tell us how the firm will move from its initial position (I_0, T_0) towards a steady state position (1, 1) from where no further changes will be beneficial.

The intermediate paths in between these two extreme positions can be analyzed by taking the time derivative of each path:

$$\dot{I}(t) = \tfrac{1}{4}e^{-t}\left(2T_0 - 2I_0 - e^{t/2}\left(I_0 + T_0 - 2\right)\right) \tag{A9}$$

$$\dot{T}(t) = \tfrac{1}{4}e^{-t}\left(2I_0 - 2T_0 - e^{t/2}\left(T_0 + I_0 - 2\right)\right) \tag{A10}$$

These functions describe the firm's optimal rates of change at each point in time, given its *initial* levels of international scope and technological knowledge. However, they can be simplified dramatically by expressing them as functions of *current* levels instead. Intuitively, at each point in time, the firm faces a new optimization problem with the same profit function and (infinite) time horizon as in the original one. This means that, by substituting $t = 0$ into Equations (A9) and (A10), we derive a more useful description of what a firm will do at a given point in time (normalized to 0) as a function of its levels of international scope and technological knowledge *at that time*. This results in the following equations (2) and (3) in the paper. A mathematical proof of this result can also be obtained by proposing $\dot{I}_{\hat{t}} = \frac{1}{2} - \frac{3}{4}I_{\hat{t}} + \frac{1}{4}T_{\hat{t}}$ as the optimal rate of change at time $\hat{t}$, substituting the known levels of $I(\hat{t})$ and $T(\hat{t})$ from Equations (A7) and (A8) into that expression, and simplifying it to end up with Equation (A9) (and repeating the process for *T*).