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Entrepreneurship in the Theory of the Firm

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ABSTRACT. This paper develops micro-economic foundations for a theory of entrepreneurship and growth, focusing on innovation and opportunity as intermediate linkages between the two. Expanding upon points of tangency between Schumpeter and Coase, the paper argues that transactions costs are the glue that holds together entrepreneurial "new combinations." Technological/organizational complexity of production is defined as the extent to which a technical decision by one unit within the firm affects the productive efficiency of other units. Where decreasing transactions costs tend to pull incumbent organizations apart, the possession of difficult to imitate production practices by the same organizations keeps them together. The dissolution of incumbent firms creates opportunities for entrepreneurs; the prospect of Schumpeterian rents provides the incentive to realize those opportunities.

KEY WORDS: complexity, entrepreneurship, growth, intrafirm externalities, opportunity, production recipes, spillovers, theory of the firm.

JEL CLASSIFICATIONS: D20, D21, D23, L26, O14, O30, O31.

1. Introduction

Growth theory is built upon the neoclassical theory of the firm. An attempt to understand the relationship between entrepreneurship and growth therefore naturally begins with the question: Where does entrepreneurship – particularly Schumpeterian entrepreneurship – fit into the theory of the firm? This paper is an effort to develop micro-economic foundations for a theory of entrepreneurship and growth, focusing on innovation and opportunity as intermediate linkages between the two.[1] While I will use the generic term "entrepreneurs" throughout this paper, I am primarily concerned with the Schumpeterian notion of the entrepreneur as an innovator, as contrasted with the Kirznerian (alternately, neo-Austrian) notion of the entrepreneur as the seeker of arbitrage opportunities, or the Knightian (alternately, neoclassical) notion of the entrepreneur as the bearer of risk.[2]

The relationship between entrepreneurship and growth is the subject of a growing literature. Acs and Audretsch (1987, 1990) and Audretsch (1995), set the stage by providing empirical evidence of the significant role of small firms in generating technological innovations. Acs (1992) went further to sketch multiple pathways by which entrepreneurial activity drives economic growth. Schmitz (1989) offered a formal model of this process in which the entrepreneur is represented as an imitator of incumbents. More recently, Acs and Armington (2004) empirically assessed the role of entrepreneurs in promoting knowledge spillovers and growth at the scale of a city. Acs and Varga (2005) and Stel et al. (2004) both employed data from the Global Entrepreneurship Monitor (GEM) project to study the relationship between entrepreneurship and growth at the scale of the nation. Michelacci (2003) and Acs et al. (2006) explored the role of entrepreneurs as knowledge "implementors" or "filters," respectively, and the manner in which those functions drive economic growth. Weitzman (1998) and Michelacci (2003) presented models in which the ultimate limits to growth will lie not in the generation of inventions and new fundamental knowledge that "spills overs" from one part of the economy to another, but rather in the availability of

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Schumpeterian entrepreneurs to guide the conversion of those inventions and new knowledge into practice through innovation.

Where these recent papers (with the exception of Weitzman, 1998) have taken the macroeconomic literature as the point of the departure,[3] I start with role of the entrepreneur in the theory of the firm, and sketch potential causal pathways "from the ground up." In a spirit similar to Foss and Klein (2005), I argue that a substantial and instructive overlap exists between the respective theories of the firm of Schumpeter (1912) and Coase (1937) as each relates to entrepreneurship. I argue that the two theories considered jointly are consistent with a characterization of entrepreneurs as seekers of solutions of hard combinatorial problems – creators of "new combinations" in a world where only a few of all possible combinations improve on existing practice.[4]

To link the Coasean theory of firm to entrepreneurship (and ultimately to growth), I need to be able to differentiate formally the sort of "hard problems" that I claim are solved by entrepreneurs from easy problems whose resolution does not create opportunity for Schumpeterian profits. Informally, this is a familiar distinction. Both academics and policymakers routinely differentiate two sorts of opportunity entrepreneurship: "high-tech," presumably involving innovation, and "low-tech," involving only the application of known and little-changing techniques.[5] However, the terms "high-tech" and "low-tech" can be confusing. A local print shop might be considered a "high-tech" firm to the extent that its activities integrally involve the use of complicated technologies. However, the organization itself is not complex, and its practices are easily imitated. Viewed from the standpoint of economic fundamentals, the problem solved by a print shop owner is a simple one as compared with those solved by an aircraft manufacturer, a biotech firm, or a large retail operation (such as Wal-Mart).

My approach therefore is not to focus on the technology in use within a firm, but rather on the technological/organizational complexity of the firm taken as a whole. Simon (1969, p. 195) describes complex systems as being constituted of "a large number of parts that interact in non-simple ways ... [such that] given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole." In the same spirit, I define the technological/organizational complexity of production as the extent to which a technical decision by one unit within the firm affects the productive efficiency of other units. The modeling structure is based upon Kauffman and Levin's (1987) *NK* model of "fitness landscapes," applied previously to production theory, organizational theory, and industrial economics but until now not to the study of entrepreneurship.[6] I conjecture that the complexity of production affects firm learning and imitation – and thus the magnitude of Schumpeterian profits – in two related ways. Both incumbents and new entrants faced with more complex production tasks have a relatively difficult time finding improvements to current methods. At the same time, those firms that do find "solutions" to difficult production problems are not easily imitated, as small errors in "copying" by entrants will result in large changes in outcomes (measured in terms of efficiency). In this way the magnitude of technological complexity is a core parameter in the economy, determining the magnitude of incentives to convert inventions into innovations, and thus the link between entrepreneurship and growth via opportunity.

The organization of the paper is as follows. In Section 2, I briefly describe points of tangency between Coase (1937, 1960) and Schumpeter (1912) relating to entrepreneurship in the theory of the firm. In Section 3, I introduce the production recipes model of technological innovation. In Section 4, I describe two limiting cases of innovation: imitation of an incumbent by a "spin-off" firm and "innovation-by-doing." I differentiate both from invention. In Section 5, I conclude by describing three directions for empirical work suggested by the paper: constructing theoretically derived measures of technological/organizational complexity to differentiate "high-tech" from "low-tech" firms and industries; better understanding the respective dynamics of "high-tech" and "low-tech" industries; and studying the manner in which the internal structure of firms is endogenously determined in the process of market competition, alternately creating and eliminating possibilities for new firm formation and growth.

2. Linking Schumpeterian and Coasean theories of the firm

According to Coase (1937, p. 390), the task of theorists of the firm is "to attempt to discover why a firm emerges at all in a specialized exchange economy." At the outset, a link to entrepreneurship is suggested: asking why "a firm" emerges in a market economy is, after all, not very different from asking why or under what circumstances a *new* firm emerges. Coase's answer focuses on the cost of using the price system to organize production[7] as compared with the alternative of managing transactions within a newly created firm:

> Outside the firm, price movements direct production, which is coordinated through a series of exchange transactions on the market. Within a firm these market transactions are eliminated, and in place of the complicated market structure with exchange transactions is substituted the entrepreneur-coordinator, who directs production. (Coase, 1937, p. 388)

For a given production activity, if the cost of creating a new firm is lower than that of using the price system, an entrepreneurial opportunity exists. If an entrepreneur acts to realize this opportunity, s/he will create a new firm. The scope of the firm will be determined by the costs of relevant transactions.[8] Where further opportunities exist, the entrepreneur will expand the number of transactions within the firm, enlarging span of control, to realize economies of scope: "As more transactions are organized by an entrepreneur, it would appear that the transactions would tend to be either different in kind or in different places."[9] In the process of expanding the scope of the firm, the entrepreneur diversifies the firm's activities.

Coase (1937, p. 397) uses the terms "combination" and "integration," respectively, to refer to horizontal and vertical mergers:

> There is a combination when transactions which were previously organised by two or more entrepreneurs become organised by one. This becomes integration when it involves the organisation of transactions which were previously carried out between the entrepreneurs on a market. A firm can expand in either or both of these ways.

Coasean entrepreneurs thus create "new combinations," in the Schumpeterian sense, by either organizing within a new firm activities previously carried out by different firms, or expanding the scope of an existing firm to incorporate activities previously related through the market.

3. Production recipes and intrafirm externalities

What is the nature of these "new combinations" that entrepreneurs create? They are combinations of particular activities that jointly constitute the organization as a whole – "routines" in the language of Nelson and Winter (1982),[10] "organizational capabilities" in the language of Chandler (1990, 1992),[11] and "production recipes" in the language of Winter (1968) and Auerswald et al. (2000).[12]

In this paper, I employ "recipes" as the term of choice to relate the entrepreneurial creation of new combinations to production theory:[13]

$$\text{creating new combinations} \Longleftrightarrow \text{creating new production recipes.}$$

Formally, denote the recipe by ω. The recipe ω is comprised of a set of N distinct activities each carried out in a particular way:

$$\omega = (\omega^1, \ldots, \omega^i, \ldots, \omega^N),$$

where ω^i represents the instructions for activity i.[14]

Any recipe that has been tried is associated with a particular level of organizational capital θ. As in Prescott and Visscher (1980), organizational capital refers to "information as an asset of the firm" – the sum of the knowledge, much of it likely tacit, involved in production.[15] Organizational capital collapses the details of the firm's internal activities into a single number. It is the direct analog of "fitness" in an evolutionary model. In a linear specification, the value of organizational capital is given as θ

$$\theta(\omega) = \sum_{i=1}^{N} \theta^{i,-i}(\omega^i),$$

where $\theta^{i,-i}(\omega^i)$ is the contribution to organizational capita of activity ω^i when carried out in a particular way, conditional on the manner in which the other activities (represented by the superscript "$-i$") are carried out.[16]

To emphasize: The organizational capital represented in a given activity depends on the chosen instructions for that activity and possibly on the instructions for some (but not necessarily all) of the other activities. Why? Coase (1960) provides the motivation: when entrepreneurs act to create or expand a firm in the manner described above they "internalize externalities," incorporating into the firm precisely those activities for which contracts are difficult to negotiate, for example due to multiple contingencies or high degrees of intrinsic uncertainty. This is critical. If the firm's internal resources can be allocated more effectively through the market, then no function exists for the "entrepreneur-coordinator" to whom Coase refers; presumably in a competitive environment he will earn zero return for his efforts.

The internalization of externalities, which is the premise of the existence of the firm to begin with, means that distinct units of the firm brought together by the entrepreneur are inter-dependent. Finding the optimal configuration of a firm's activities is much like finding the solution to a Rubik's cube puzzle: the creation, expansion, and management of the firm is made difficult by the fact that modification to the practices of one unit will affect the effectiveness of other units. Indeed, if one particular unit of a firm is not linked to any other via such "intrafirm externalities," then we can reasonably wonder why that unit is part of the firm to begin with (rather than, for example, acting as an outside contractor). Entrepreneurs and firm managers are thus typically charged with solving complex coordination problems.[17]

Specifically, denote by e the magnitude of intrafirm externalities within a firm. This is the key parameter in the paper.[18] In a more complete treatment consistent with the above discussion of Coase (1937, 1960), e would be determined endogenously by a dynamic process of entrepreneurial entry and exit that would create distinct technological/organizational types at the firm level. Different firms in the same industry may be characterized by different magnitudes of intrafirm externalities. To focus attention on the manner in which different levels of technological/organization complexity affect opportunity and growth, in this paper I assume that e is exogenous – determined by the engineering and other technical principles underlying production in a given industry. With this assumption the parameter e can serve to distinguishing one industry from another. Three types of industries are possible:

- $e = 1$ **(zero intrafirm externalities)**. One limiting case is that in which there are no intrafirm externalities: A change in the production method employed by *one* of the N production units within the firm affects the efficiency *only* of that *single* unit. Each unit is "linked" to exactly one unit: itself. The average level of interconnection of the firm's production units, e, therefore is equal to 1.
- $1 < e < N$ **(intermediate complexity)**. Values of e such that $1 < e \le N$ characterize production over a range of industries where a change in the production method by *one* of the N production units in the firm affects the efficiency of that unit, as well as *some*, but *not all*, of the other $N-1$ production units. In this range of industries the level of complexity of production (the average linkage of the firm's production units) is increasing in e. The argument above suggests that most industries fall in this category.
- $e = N$ **(total intrafirm inter-connection)**. The limiting value $e = N$ represents the case of maximal complexity: a change in the production method by *one* of the N production units within the firm affects not only that unit, but *all* of the other production units as well.

Figure 1, derived from Ulrich and Pearson (1998), provides an example. Here the activities in an enterprise producing coffee makers are identified as assembly, sheet metal cutting, and plastic moulding. As there are three activities, $N = 3$. The

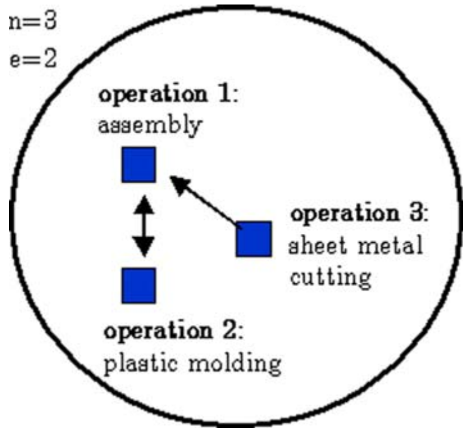

Figure 1. An example of intrafirm externalities: $N = 3$, $e = 2$.

nature of the linkages between the activities is illustrated in the figure. While here conjectured, they are potentially discoverable by empirical study. In this example, the manner in which sheet metal cutting and plastic molding take place both have an effect on the efficiency of assembly. This accounts for two intrafirm external effects, or linkages. The manner in which assembly take place does not affect efficiency outcomes for sheet metal cutting. However, in this example, assembly does affect plastic moulding – for example, because of physical proximity of machinery. This is a third intrafirm linkage. By definition, each activity is ''connected'' to itself, which adds three more intrafirm linkages. The total number of intrafirm linkages is six. Consequently, e, the average number of intrafirm external effects, or linkages, is $\frac{6}{3}$, or 2.

4. Two limiting cases of innovation

4.1. *Imitation*

I have detailed above how the existence of intrafirm externalities is directly implied by Coase (1937, 1960) – the fundamental framework in economics for understanding the theory of the firm. The presence of intrafirm externalities suggests that the transfer from one firm to another of knowledge regarding production – the essence of the concept of ''instructions'' that is the core of Romer (1986, 1990) – is far more likely to be costly and subject to errors than it is to ''spill-over'' costlessly between firms.[19] The same is true even if the knowledge is codified: while codified knowledge may be non-rivalrous, in most cases it is either excludable (patents, documents protected by trade secret) or not directly applicable to production (basic research papers). The exceptional cases of published, unprotected ''designs'' are not likely to offer significant opportunities for Schumpeterian entrepreneurs unless combined with other information in novel, and not easily imitable, ways.[20] Furthermore, patent protection is available to innovators in all industries, yet significant inter-industry differences exist in the extent to which patents allow for persistence of profits. As Henderson et al. (1999) observe:

> [R]apid imitation of new drugs is difficult in pharmaceuticals for a number of reasons. One of these is that pharmaceuticals has historically been one of the few industries where patents provide solid protection against imitation. Because small variants in a molecule's structure can drastically alter its pharmacological properties, potential imitators often find it hard to work around the patent. Although other firms might undertake research in the same therapeutic class as an innovator, the probability of their finding another compound with the same therapeutic properties that did not infringe on the original patent could be quite small.

With regard to codified knowledge that is partially excludable, a critical issue is the extent to which partial imitation, or copying, preserves the quality of the original. In many, perhaps the majority, of economically important contexts it will not.

In this light, consider the actions of a new entrant in a sub-industry defined around a single good with well-defined, uniform characteristics. The new entrant can either

- imperfectly imitate the incumbent, inadvertently altering a certain number, denoted by δ, of the N activities in the incumbent's production recipe;
- differentiate itself by innovating new approaches to δ of the N activities in the recipe; or
- undertake some combination of both approaches, leading to changes in δ of the N activities in the recipe.

The parameter δ is thus the measure of either the extent of imperfections in imitation, the scope of search using existing practice as a point of reference, or a combination of both. Which of these three options holds is less significant than the observation that, in most cases, the entrepreneurial new entrant will be either unwilling or unable to copy perfectly an incumbent's production recipe. In the case where δ is systematically large relative to *N*, there is little transferability of knowledge from the incumbent to the new entrant for the trivial reason that the entrant essentially ignores or is unable to grasp the existing organizational knowledge in the industry.

Without ruling out the possibility of "radical innovators" aggressively seeking dramatically new solutions to the problem of production, I focus here on the limiting case in which the new entrant is very nearly able to copy the production method of the incumbent firm: the new entrant seeking to copy an incumbent modifies exactly one out of the *N* activities in the incumbent's production recipe. Let us refer to this limiting case as that of an entrepreneurial "spin-off" firm. The results that hold for the spin-off firm highlight the central role in the model of intrafirm externalities – that is, of the complexity of production – and thus provide a point of reference for understanding the behavior of other entrepreneurial new entrants.

The spin-off enters the industry with a production recipe that is very close to that of the incumbent. However, due to the presence of intrafirm externalities, the organizational capital of the spin-off may be very distant from the incumbent's. The spin-off's modification of the instructions for a single operating unit will affect the performance of exactly *e* other units within the firm. The organizational capital level associated with the spin-off firm's production recipe thus takes on the following stochastic form:

$$\theta_t^{\text{spin-off}} = \underbrace{\frac{(N-e)}{N}\theta_t^{\text{incumbent}}}_{\text{unaffected by imitation}} + \underbrace{\frac{1}{N}\sum_{i=1}^{e}\phi^i}_{\text{affected by imitation}} \qquad (1)$$

where the φ^{i}'s are i.i.d. random variables drawn from a distribution $g(\varphi)$ with mean μ which is common knowledge to all firms.

The first term on the RHS of equation 1 represents the component of the spin-off firm's initial stock of organizational capital (or efficiency) that is *unaffected* by the imperfect imitation. This unaffected component roughly represents a fraction $\frac{N-e}{N}$ of the firm's total efficiency level. Note that the fraction of the firm's efficiency that is *unaffected* by the imperfect imitation is decreasing in the complexity of production.

The second term on the RHS of equation 1 represents the contribution to the spin-off firm's stock of organizational capital (or efficiency) of the *e* units that are *affected* by imitation. I model the contribution to the firm's efficiency of the affected components simply as the summation of *e* independent and identically distributed random variables. Implicit in this construction is the view that firms experience as random events shocks to efficiency at the level of the production unit (that is, at the organizational scale that lies below that of the firm as a whole) resulting from incremental changes in production methods.[21]

The higher the value of *e*, the lower the correlation between the incumbent's stock of organizational capital and that of the nearly perfectly imitating start-up firm. Consequently the higher the value of *e*, the greater the difficultly (ease) of finding an improvement to a high (low) efficiency production method. Importantly, the organizational capital of the spin-off firm may be greater, equal to, or less than the organization capital of the firm being imitated. In other words, it is possible for the "imitator" to surpass the leader. The likelihood that this will occur is a function both of the leader's organizational capital, and of *e*, the level of intrafirm externalities.

4.2. *Innovation by doing*

Having defined recipes and intrafirm externalities, I need only to specify a process by which experimentation occurs in order to complete a micro-economic representation of technological/organizational innovation.

At any time period t,[22] some subset of the N teams comprising an incumbent firm informally experiments with a change to its method of production for a given activity. This change results in a "trial" production recipe. An incumbent firm's managers can pay c_t^{lbd} to a quality control manager to learn θ_t^{lbd}, the *overall* efficiency of the firm given the trial method of production.[23] In the absence of supervision, the experiment is dropped and forgotten. In the presence of supervision, the firm learns θ_t^{lbd}. In the next time period it can either maintain it's current method of production (and thus current efficiency level, θ_t), or adopt the newly tried method (thus achieving efficiency θ_t^{lbd}). The firm will make the choice that gives it the highest level of efficiency at any time, thus

$$\theta_{t+1} = \begin{cases} \max\{\theta_t, \theta_t^{\mathrm{lbd}}\} & \text{with learning "supervision";} \\ \theta_t & \text{without.} \end{cases} \tag{2}$$

In Figure 2, I present a timeline summarizing the sequence of events in the learning process within a single period.

Where the parameter δ above indicated the extent to which imitation is imperfect, the parameter e (intrafirm externalities) indicates the extent to which *any* modification of the firm's existing production recipes will have broad impacts on the firm's organizational capital. Where the incumbent firm can reasonably be expected to "imitate" itself more effectively than an entrepreneurial new entrant, it cannot escape the technological/organizational fundamentals that are represented by the parameter e. For this reason, a symmetry exists between the effect of the parameter e on the effectiveness of imitation by a spin-off firm, and the effect of the same parameter on learning by an incumbent firm. The correlation between θ_t (current organizational capital) and θ_t^{lbd} (the organizational capital associated with the production experiment) depends on e, the magnitude of intrafirm externalities (i.e., the complexity of the production process) in the following manner:

$$\theta_t^{\mathrm{lbd}} = \underbrace{\frac{(N-e)}{N}\theta_t}_{\text{unaffected by time } t \text{ lbd}} + \underbrace{\frac{1}{N}\sum_{i=1}^{e}\phi^i}_{\text{affected by time } t \text{ lbd}} \tag{3}$$

where as before, the φ^i's are i.i.d. random variables drawn from a distribution $g(\varphi)$ with mean μ which is common knowledge to all firms. Equation 3 formally expresses the effect on learning of the presence of intrafirm externalities. Roughly speaking, the higher the value of e, the lower the correlation between current efficiency and the efficiency associated with a production experiment. Consequently the higher the value of e, the greater the difficultly (ease) of finding an improvement to a high (low) efficiency production method. I present the formal proposition in Appendix C.

In the sample learning curves and simulation results presented in Figures 3–5, $g(\varphi) = $ Uniform[0, 1] ($\mu = 0.5$). Figure 3 presents means and standard deviations of learning rates[24] computed from 12 sets of 20 separate simulated learning curves. Each set represents one industry, characterized by its own value of e. The figure shows that mean simulated learning rates decline as the complexity of production in an industry increases.

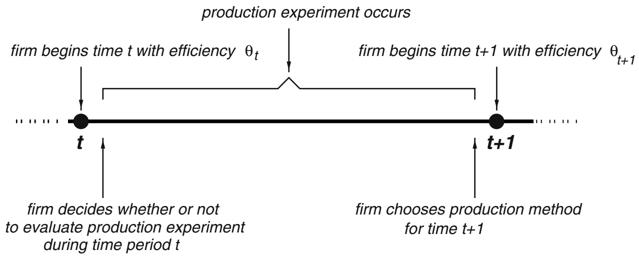

Figure 2. Sequence of events in a single time period.

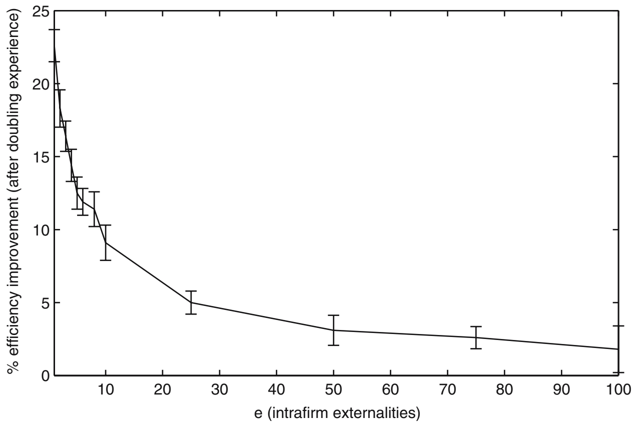

Figure 3. Percent improvement in efficiency after experience is doubled, e (magnitude of intrafirm externalities) varied. ($N = 100$, g (φ) = Uniform[0, 1], $\mu = 0.5$.) From Auerswald et al. (2000).

Figures 4 and 5 display simulation results for single realizations of learning curves generated from an innovation by doing process. In industries where production is simple ($e = 1$), the efficiency of any given production method is highly correlated with that of "similar" production methods – precisely, production methods that differ only with respect to the approach taken by one of the N production units. Figure 4 illustrates: a representative learning curve ($e = 1$, $N = 100$) is smooth and initially steep, but evidences sharply diminishing returns. Small changes in the production method lead to small changes in productive efficiency (on the order of $\frac{1}{N}$). To the extent that N is large, learning will appear to be nearly deterministic as small efficiency gains cumulate in a regular manner over an extended period of time.

In contrast, in the limiting case for industries where production is maximally complex ($e = N$), similar production methods are wholly uncorrelated with one another in terms of efficiency. Figure 5 illustrates: with parameters set at $e = 100$, $n = 100$, improvements are rare and gains minimal. *Any* change to the production method leads to an entirely new efficiency level. The resulting "learning" process is highly disjointed. Though extreme in the context of a model

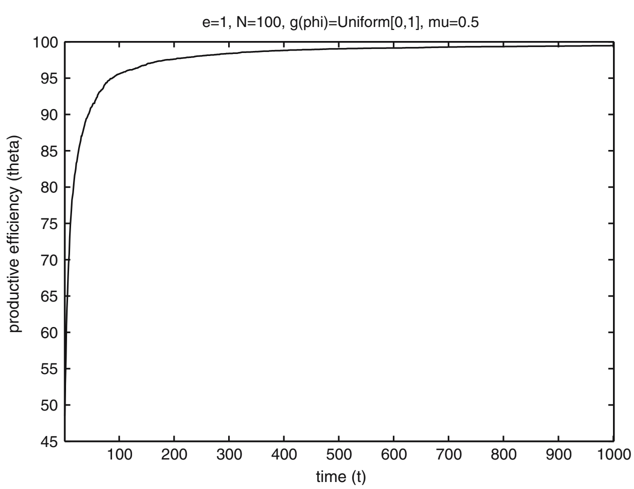

Figure 4. Industry with simple production process ($e = 1$): typical firm learning curve.

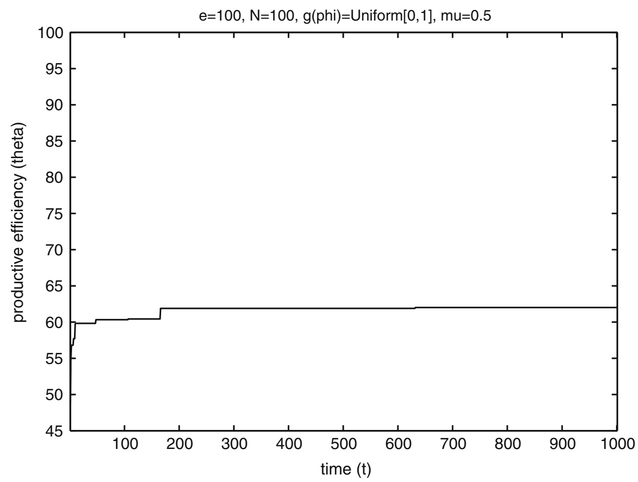

Figure 5. Maximally complex production ($e = 100$): typical firm learning curve.

of firm learning with intrafirm externalities, this limiting case is the default in most of the firm learning literature in economics as exemplified by the classic papers of Evenson and Kislev (1976) and Telser (1982).

The simulated learning curve displayed in Figure 6 illustrates the innovation by doing process in an industry characterized by production of intermediate complexity ($e = 5$, $N = 100$). Auerswald et al. (2000) calibrate a generalized innovation by doing model to the quantitative and qualitative features of a modal empirically observed learning curve.[25] They find that, in the typical manufacturing industry, parameter values corresponding to intermediate complexity yield the best fit. The implication is that each operating units in a typical firm interacts directly with approximately 5% of the other operating units. The resulting process of firm learning is relatively irregular but nonetheless results in significant efficiency gains over time, with a doubling in output expected to result in a cost reduction of approximately 20%.

4.3. *Differentiating invention from innovation*

A production recipes model offers one approach for clearly distinguishing between genuine novelty (which is rare) and innovation through the creation of new combinations (which is relatively common, and occurs along a potentially measurable spectrum[26]). Contributors to

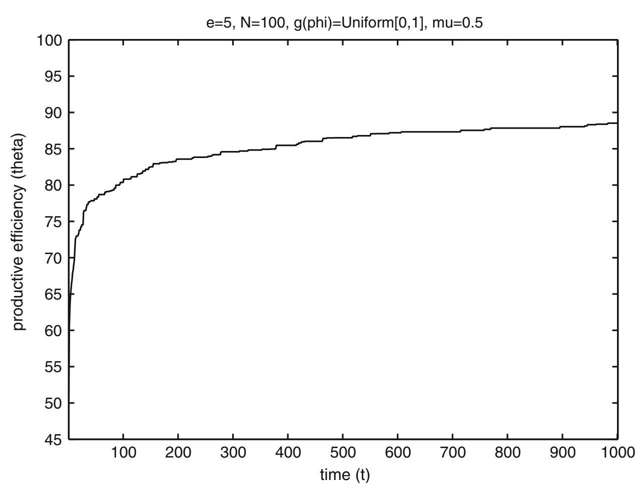

Figure 6. Industry with moderately complex production process ($e = 5$): typical firm learning curve.

literatures on entrepreneurship and technical change have long distinguished ''imitation'' from ''innovation.''[27] A common presumption is that Schumpeterian entrepreneurs are innovators, not imitators.[28] However, the more fundamental distinction is that between invention (alternately, ''novelty'') and innovation (or the ''mechanism'' by which novelty is transmitted).[29]

In the production recipes model, invention corresponds to the creation of new activities – fundamentally new building blocks from which ''combinations'' are derived. In a cooking analogy, the activities could be stirring, baking, rolling, slicing, and so forth. Excluding newly added elements, the set of activities is widely known. Recipes are combinations of these activities.

In contrast, ''innovation'' is the creation of new recipes from a fixed set of activities. Just as software engineers routinely combine tested segments of code (in existing programming languages!) rather than constructing complex programs entirely *de novo*, entrepreneurs routinely combine existing activities rather than inventing fundamentally new categories of economic action.[30]

5. Conclusion

In this paper I have proposed a firm-level representation of the innovation process. I began by emphasizing the manner in which transactions costs define opportunities for the creation by entrepreneurs of technological/ organizational ''new combinations.'' I argued that transactions costs are the glue that holds together entrepreneurial new combinations. Knowledge intensive entrepreneurial firms come into existence when transactions costs are relatively high, not when they are low or zero. Furthermore, when transactions costs decrease in some parts of the economy relative to others, we expect to observe reconfigurations of economic activity and the subsequent entry and exit of Coaseanially affected firms.[31]

As with any theory, this paper's primary intended contribution is to frame future empirical study. The paper suggests three primary directions for further research.

The first concerns measurement. The ubiquity of the term ''high-tech'' in the research literature (as elsewhere) would seem to suggest that a theoretically based consensus exists as to its meaning. In fact, no such consensus exists. The literature contains several conventions. One is to focus on research intensity – for example, employing average levels of R&D as a percentage of sales to differentiate high-tech from low-tech industries. While this approach has some intuitive appeal, it is not at all clear that research inputs are the right measure: traditional manufacturing industries such as chemicals that exhibit relatively high R&D to sales ratios may not be significantly more ''high-tech'' than financial and other service industries that do not. An alternative is to employ as a measure the intensity of investment in information technology. This measure has the advantage of recognizing the potential for service industries to be ''high-tech'' and is a reasonable proxy for industry-wide changes in transactions costs. However, again, a theoretical rationale is lacking.

A production recipes model offers an approach for formally differentiating ''high-tech'' from ''low-tech'' firms that is theoretically grounded. Recipes as described in this paper are neither purely technological nor purely organizational. They are both. An example illustrates why this is important. Weitzman (1996) eloquently describes the manner in which the ''hybridization of ideas'' played a central role in Edison's invention of the ''electric candle;'' along the same lines he elsewhere has observed that ''once you have nuclear power and you have a submarine, it is almost inevitable you're going to have a nuclear submarine.''[32] Yet the development of the first nuclear submarine also required radical changes in the Navy itself. What is more, implementing those radical changes required nearly dictatorial coordination on the part of the project's champion, Admiral Hyman Rickover.[33] Although the combination of ''nuclear'' and ''submarine'' may, in some long-term, statistical sense have been ''inevitable,'' realizing the potential of that particular combination at a singular point in time required the vision and determination of an entrepreneur – one capable of creating new technological and organizational combinations.[34] Due to its combined technological and organizational complexity, the creation of a nuclear Navy was a legitimately ''high-tech'' activity. In general, a rich research agenda exists in the use of measures derived from the internal organization of firms – for example, the intrafirm externalities (e) in this paper – as a way of differentiating "high-tech" from "low-tech" firms.

A second research agenda would explore implications for industrial organization, particularly the manner in which "high-tech" (technologically/organizationally complex) and "low-tech" (technologically/organizationally simple) industries exhibit different patterns of entry, exit, and evolution. The definitions presented in this paper seem to suggest that in industries where production processes are simple, we would expect profits to converge rapidly to zero, particular when imitation is possible. In industries where production processes are more complex, persistent Schumpeterian profits may accrue to surviving firms. Schumpeterian profits, and thus entrepreneurial opportunity, consequently may be greatest industries in the early stages of industries where technology is of intermediate complexity – that is, where learning is rapid enough to confer competitive advantage, but imitation is sufficiently uncertain to deter later entry.

A more complete model would take the demand side seriously, recognizing that the bulk of process innovation and a considerable amount of entrepreneurship involves making incremental changes to existing recipes, motivated by direct engagement in the marketplace. Many of the firms that have in recent years forced significant market transformations (from Ebay to Napster) are engaged in the same sort of market, as opposed to technology, based opportunity exploitation that has been the norm for most economic history. Furthermore, as Henderson and Clark (1990) argued some time ago (in different terms), there is no strong relationship between the magnitude of change to a recipe and the resultant market impact: small modifications to recipes and/or in the associated "product architecture" can result in dramatic dislocations in the marketplace. Conversely, as Christensen (1997) famously documented for the case of the disk-drive industry, recipes that involve high levels of technological complexity may create products which are essentially commoditized in the marketplace.

A third research agenda – the one with the most potential significance for the study of entrepreneurship – would involve treating the magnitude of intrafirm externalities as an endogenous variable and studying its determinants, importantly including transactions costs. Unsurprisingly, the internal structure of firms is a topic that has been explored more thoroughly in the management literature than in economics. Even in management, there has been little study of the effect of transactions costs on technological/organizational complexity and on the process of entry and exit. A notable exception is the paper by Brynjolfsson et al. (1994), who find evidence that investments in information technology at the scale of an industry lead to a decrease in average firm size. Evans and Wurster (1999) present a more general argument, describing the manner in which changes in transactions costs brought about by the Internet are driving organizational change across multiple industries. Rivkin (2000) explores the implications for management strategy, describing how complex strategies resist imitation.

Where decreasing transactions costs pull incumbent organizations apart, the possession of difficult to imitate production recipes by the same organizations keeps them together. The dissolution of incumbent firms creates opportunities for entrepreneurs; the prospect of Schumpeterian rents provides the incentive to realize those opportunities. The two factors are in tension. In developed economies, competitiveness at the national scale is a function of innovation and adaptability: the possession of capabilities that are difficult to imitate and the ability to capitalize rapidly on opportunities created by technological change.[35] For this reason, a representation of the innovation process that accounts for transactions costs and technological/organizational complexity is a pre-requisite for a formal theory of entrepreneurship and growth.

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presented. Appendices A and B are drawn from Auerswald et al. (2000). All errors are my own.

Appendix A. The technology landscape as a realization of a random field

We assume that the unit labor cost of activity i, $\varphi^i(\omega)$, is a random variable whose distribution function is defined on R_+. Consider two distinct recipes, ω and ω'. The random variables $\varphi^i(\omega)$ and $\varphi^i(\omega')$ are not necessarily independent. In fact, φ^i depends on the instructions, ω^i, for activity i and possibly on (some of) the instructions for the other activities, ω^{-i}. (With minor abuse of notation, one could then have denoted the unit labor costs of activity i by $\varphi^i(\omega^i; \omega^{-i})$, or more simply, $\varphi^i(\omega)$.) We assume that the labor requirements are additive; hence we have

$$\phi(\omega) = \sum_{i=1}^{N} \phi^i(\omega),$$

where $\varphi(\omega)$ is the unit cost of production employing recipe ω. For ω fixed, $\varphi(\omega)$ is a random variable. If ω is allowed to vary over the set of all possible recipes, Ψ, then $\varphi(\omega)$ is a *random field*. A random field is a slight generalization of a stochastic process to allow the argument (in this case ω) to be a vector (as opposed to being a scalar such as "time"). For the special case in which $N = 1$, $\varphi(\omega)$ is then an ordinary stochastic process. We denote by $\theta^{i,-i}(\omega)$ the realization of the random variable $\varphi^i(\omega)$. The realization of the random variable $\varphi(\omega)$ is $\theta(\omega) = \sum_{i=1}^{N} \theta^{i,-i}(\omega)$. If ω varies over Ψ, the family of realizations $\theta(\omega)$ is called the *landscape* (of the random field $\varphi(\omega)$). A landscape is thus a generalization to the case with $N > 1$ of a "history" (of a stochastic process).[36]

Appendix B. Formal definition of intrafirm externalities

A bit more notation is required to get the concept of production recipes into the model. Define the connectivity indicator e_j^i by

$$e_j^i = \begin{cases} 1 & \text{if the choice of setting for activity } i \text{ affects the labor requirement for activity } j \\ 0 & \text{otherwise} \end{cases}$$

for $i, j = 1,...,N$. Since the choice of the setting for the ith activity always affects the costs for the ith activity, we have

$$e_i^i = 1$$

for $i = 1,...,N$. The number e^i of activities with costs affected by activity i is given by

$$e^i = \sum_{j=1}^{N} e_j^i$$

for $i = 1,..., N$, while the number e_i of activities that affect the costs of activity i is given by

$$e_i = \sum_{j=1}^{N} e_i^j$$

for $i = 1,..., N$. Define E_i, the set of activities cost-relevant to activity i, by

$$E_i = \{j \in \{1, \ldots, N\} | e_i^j = 1\}$$

for $i = 1,..., N$.

In general, each activity could be cost-affected activity is cost-affected by $(e-1)$ other activities, so that we have

$$\#E_i = e_i = e$$

for $i = 1,..., N$, where $e \in \{1, \ldots, N\}$.

Appendix C. Complexity, learning, and imitation

Consider the firm's expectation regarding θ_t^{lbd}, given by

$$E(\theta_t^{\text{lbd}} | \theta_{t-1}, e) = \frac{(N-e)}{N}\theta_{t-1} + \frac{e}{N}\mu. \tag{4}$$

With some departure from mathematical precision, I take the partial derivative equation 3 with respect to e (which is integer valued) to express the effect of e on $E(\theta_t^{\text{lbd}})$:

$$\frac{\partial[E(\theta_t^{\text{lbd}})]}{\partial e} = \frac{\mu - \theta_{t-1}}{N}.$$

Consequently

$$\frac{\partial[E(\theta_t^{\text{lbd}})]}{\partial e} \begin{cases} \leq 0 & \text{if} \theta_{t-1}\mu, \\ 0 & \text{otherwise.} \end{cases} \tag{5}$$

This rough result reinforces the intuition behind part (iii) of proposition 1 below: the higher the level of intrafirm externalities, the greater the likelihood that a relatively efficient firm will be difficult to"imitate," even by a well-informed spin-off firm.

In order to formally express this relationship, I express the probability that θ_t^{lbd} is lower than some number z as

$$\Pr\left(\theta_t^{\text{lbd}} \le z|\theta_{t-1};e\right) = H(z|\theta_{t-1};e) = \int_0^z h(z|\theta_{t-1};e)dz$$

where H $(z|\bullet)$ denotes the cumulative density function and h $(z|\bullet)$ denotes the probability density function. $H(\theta_t \; |\theta_{t-1}, \; e)$ represents the probability of *failure* of a firm to find an improvement on method θ_{t-1} in a single trial. We can write the firm's expectation of its productive efficiency in the next period precisely as

$$E(\theta_t|\theta_{t-1};e) = \theta_t H(\theta_t|\theta_{t-1};e) + \int_{\theta_{i,t}}^{\infty} zh\left(z|\theta_{i,t-1};e\right)dz. \quad (6)$$

The following proposition specifies some properties of the distribution H $(z \mid \theta_t, \; e)$.

Proposition 1 (Properties of the Distribution of Outcomes from Imitation) *H $(z|\theta_{t-1}; \; e)$ is (i) stochastically nondecreasing in θ_{t-1} for $e < N$; (ii) not a function of θ_{t-1} for $e = N$; (iii) stochastically non-decreasing in e for $\theta_{t-1} > \mu$, and stochastically non-increasing in e for $\theta_{t-1} < \mu$.*

Proof.

i. If $e < N$, neighboring production methods are correlated: a fraction $(N-e)/N$ of the activities of any one neighbor variant of ω_{t-1} will be in the same states as the corresponding activities in ω_{t-1}.[37] Consequently, for e < N, H (z | θ_{t-1}, e) will shift to theright with increasing θ_{t-1}.
ii. When $e = N$ the correlation between neighboring production methods is 0. Therefore

$$h(z|\theta_{t-1}, e = N) = h(z|e = N).$$

iii. e parametrizes the correlation between θ_t^{lbd} and θ_{t-1}. If $\theta_{t-1} > \mu$, increasing e moves h $(\bullet)$ to the left, towards the unconditional distribution h $(z \mid e = N)$. If $\theta_{t-1} < \mu$, increasing e moves h $(\bullet)$ to the right, again towards h $(z \mid e = N)$. □

Notes

1 Expanding upon Acs (1992), Wennekers and Thurik (1999) describe a set of phenomena linking entrepreneurship to growth, including: creation of new markets; newness through start-ups; invention and innovation; variety and selection of ideas; markets and competition; disequilibrium; and replacement of obsolete enteprises.

2 The definition offered by Carree and Thurik (2003) provides a more comprehensive expression of what I intend: "Entrepreneurship is the manifest ability to willingness of individuals, on their own, in teams, within and outside existing organizations to perceive and create new economic opportunities (new products, new production methods, new organizational schemes, and new product–market combinations), and to introduce their ideas in the market, in the face of uncertainty and other obstacles, but making decisions on the location, form, and use of resources and institutions."

3 In particular, Romer (1986, 1990) and Aghion and Howitt (1992).

4 Reiter and Sherman (1962), Kauffman (1988), Weitzman (1996, 1998).

5 Examples of low-tech entrepreneurship might include dry-cleaning, landscaping, or copying services. The limiting case is that of franchise operations, in which techniques are fully codified.Note that both high- and low-tech opportunity entrepreneurship are distinct from "necessity entrepreneurship," in which self-employment results from an absence of alternative employment opportunities. See Acs (2006).

6 Applications of the *NK*-model to industrial economics and organizational theory include Levinthal (1997), Auerswald (1999), Kauffman et al. (2000), Rivkin (2000), and Auerswald et al. (2000). In the model that follows, my parameter *N* is directly analogous to *N* in the *NK*-model, and my parameter *e* is directly analogous to $K + 1$ in the *NK*-model.

7 Coase (1937): "The main reason why it is profitable to establish a firm would seem to be that there is a cost to using the price mechanism. The most obvious cost of 'organizing' production though the price mechanism is that of discovering what the relevant price are." The boundary of the firm is where an entrepreneurial "span of control" (Lucas 1978) ends and market transactions begin.

8 The scale of the firm will be determined by standard issues pertaining to competition, market structure, and economies of scale.

9 Coase (1937, p. 397). See also Lucas (1978).

10 Nelson (1995, pp. 68–69) describes "routines" as follows: "[F]irms can be regarded as... the incubators and carriers of 'technologies' and other practices that determine 'what they do' and 'how productively' in particular circumstances. Winter and I have used the term 'routines' to denote these."

11 Chandler's (1992, p. 86) definition of "organizational capabilities" builds upon the routines of Nelson and Winter, emphasizing the coordination of productive activities within the firm:

> [L]earned routines are those involved in functional activities—those of production, distribution and marketing, obtaining supplies, improving existing products and processes, and the developing of new ones. Even more important are those routines acquired to coordinate these several functional activities... The resulting organizational capabilities permit the enterprise to be more than the sum of its parts. They give it a life of its own above and beyond those of the individuals involved. The individuals come and go, the organization remains.

[12] Schumpeter emphasizes that production itself is a fundamentally combinatoric phenomenon. "Technologically as well as economically considered," Schumpeter wrote in the first chapter of *The Theory of Economic Development*, "production 'creates' nothing in the physical sense. In both cases it can only influence or control things and processes, or 'forces.'... [T]o produce means to combine the things and forces within our reach. Every method of production signifies some definite combination." (Schumpeter, 1912 [1961], p. 14). Echoing Shumpeter (1912) and anticipating Weitzman (1998), Kuznets (1962) opens the famed Richard Nelson edited volume on *The Rate and Direction of Inventive Activity* by proposing that an invention be defined as "a new combination of available knowledge concerning properties of the material universe."

[13] The "recipe" metaphor finds a parallel expression in Romer (1996) who observes that "non-rival ideas can be used to rearrange things, for example, when one follows a recipe and transforms noxious olives into tasty and healthful olive oil. Economic growth arises from the discovery of new recipes and the transformation of things from low to high value configurations."

[14] In particular, we assume that ω^i satisfies

$$\omega^i \in \{1, \ldots, s\}$$

for $i = 1,...,N$, where s is a positive integer. Hence, *for a given product*, the number of recipes is finite and given by

$$\#\Omega = s^n.$$

[15] Prescott and Visscher (1980, p. 446): "Information is an asset to the firm, for it affects the production possibilities set and is produced jointly with output."

[16] See appendix A, draw from Auerswald et al. (2000), for a formal description of the manner in which realizations of organizational capital define a technology "landscape" in the sense of Kauffman and Levin (1987).

[17] A classic paper by Reiter and Sherman (1962) entitled "Allocating Indivisible Resources Affording External Economies or Diseconomies," anticipates recent work (e.g., Weitzman 1998; Auerswald et al., 2000) on the firm as a solver of hard combinatorial optimization problems.

[18] The e here is directly analogous to the K in the NK-model. The parameter e can take on integral values between 1 and N. See appendix B for a formal definition of this variable.

[19] A number of factors determine the extent of transferability of technical knowledge from one firm to another. Legal restrictions – in particular, patent protection and trade secret law – clearly are important. However, as emphasized long ago by (Mansfield, 1961, 1963), even in the absence of legal barriers, the adoption of new technology is difficult and expensive. See also Mansfield et al. (1981) and Jovanovic (1995).

[20] The phenomenon of "orphan drugs" is illustrative.

[21] Here the model bears some similarity to the less purposive approaches of Simon and Bonini (1958), Hopenhayn (1992), and Atkeson and Kehoe (1997). However, where purely stochastic shocks in these papers occur at the scale of the firm as a whole, here they occur of the scale of the production unit.

[22] Presumably, the time required to produce one "batch" of output.

[23] In the case of a "pure" learning-by-doing model, $c_t^{\text{lbd}} = 0$.

[24] Specifically, the percentage increase in efficiency realized from a doubling of experience (e.g., going from the first full month to the second full month of production).

[25] See summary in Argote and Epple (1990).

[26] For the theory on this point, see Appendix C.

[27] Related is the distinction made by Cohen and Levinthal (1989) between learning (R&D directed as using existing information) and innovation (R&D directed at creating new information).

[28] For example, Carree and Thurik (2003) comment that "Schmitz (1989) was the first to present an endogenous growth model that relates entrepreneurial activity and economic growth. However, his entrepreneurs are [relatively] 'passive'... because their role is restricted to that of 'imitation.'"

[29] A recently discovered paper by Schumpeter emphasizes this point: "How does novelty come about? Why do some people happen to paint in a different way than they learned to and how is this new way of painting transferred to other painters and the public? What is on the one hand the 'energy,' if we may say so, and on the other hand the 'mechanism' of this process?" (Schumpeter, 2005, pp. 113–114) While Schumpter (2005) does not link novelty to invention, such a connection seems reasonable in light of the his observation that "[w]e find novel phenomena in the economy as in any other social domain, and there is no difference between novelty in the economy and elsewhere."

[30] Schumpeter (1912): "As a rule, the new combinations must draw the necessary means of production from some old combinations... development consists primarily in employing existing resources in a different way, in doing new things with them." As described by Kauffman (1988) and Weitzman (1996, 1998), the assumption of a fixed set of activities imposes only a weak limit on the search space for innovators, as the number possible recipes that can be derived from even a modest number of activities is hyper-astronomical.

[31] See the seminal studies of industry dynamics by Dunne et al. (1988, 1989) and Davis and Haltiwanger (1992). Whether the returns from such Coasian/Schumpeterian disruptions accrue to firms or consumers depends on the

magnitude of technological/organizational complexity within the industies in question. See Nordhaus (2004).

32 Comments at the ''Between Invention and Innovation'' workshop held at the Kennedy School of Government, Harvard, on May 2, 2001.

33 The first nuclear-powered submarine was the U.S. Nautilus, completed in 1954. Rickover is often referred to as the ''father of the nuclear Navy.'' The inter-relationship of technological and organizational innovations required to achieve this milestone is detailed in Rockwell (1995).

34 Whether individual will or inexorable ''forces'' of history cause events to occur in a particular manner is a very old question, dating in a modern form to 19th century debates over the philosophy of history involving Hegel, Marx, Nietszche, and Tolstoy (who proposes a sensible resolution in the epilog to *War and Peace*). In economics, the debate has been taken up by Nelson and Winter (1982), Arthur (1989) and others who emphasize the critical role of evolution, ''path dependence'' and historical accident over the determinism of conventional economic models. Schumpeter (2005) anticipates those discussions.

35 As Krugman (1994) pointed out a decade ago, it is easy to exagerate the imporance of innovation in developing countries (notably China), where the accumulation of quality-adjusted conventional factors of production remains the primary driver of growth.

36 See Durrett (1991, especially Chapter 2). The relationship between random field models and models based on *realizations* of random fields (i.e., landscape models) is discussed in Stadler and Happel (1995). For previous applications of random fields and landscape models to economics, see e.g., Föllmer (1974), Kauffman (1988), and Durlauf (1993).

37 As above, organizational capital is function of the particular state of the production recipe:

$$\theta_{t-1} = \theta(\omega_{t-1}).$$

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