A Theory of Entrepreneurial Behavior, Profit Opportunities, and Risks: Mathematical Derivations

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Introduction

This paper states and analyzes a theoretical model of entrepreneurial behavior. The model formalizes how characteristics of each entrepreneur drive commercialization decisions and later possible exit from commercial production. Unlike theories designed to illustrate a concept, the theory here is designed to structure an empirical test (in this case of the role of profit-seeking and risk-averse behaviors in entrepreneurs' decisions). The theory therefore must allow for the entirely different functional forms and characteristics that hold in practice for different entrepreneurs and their opportunities, i.e., it must be stated quite generally. The theory must address variables likely to be available in practice for empirical analysis, and therefore the model embodies uncertainty in only one pre- and one post-commercialization characteristic, in both cases for a type of uncertainty that might be relatively practical to measure. The model is tested in detail by Simons and Åstebro (forthcoming), who confirm the importance of pecuniary motives and risk aversion in inventor-entrepreneurs' decisions to invest in (commercialize) their ideas and later whether to exit commercial production of those ideas.

Derivations of the resulting relations between (entrepreneurs') characteristics and the resulting probabilities and hazards (of entry and exit) are not entirely trivial, and may be of a general interest. The methods used pertain to any model in which some entities' underlying characteristics affects their binary decisions such that, to an observer with only partial knowledge about the entities, there is an overall probability of a decision A, and later of a decision B given that A occurred.

Model

An entrepreneur i can pay sunk cost S_i to commercialize an idea. Absent competition, the entrepreneur then charges price p_i, pays fixed cost flow F_i per year plus average variable production cost c_i, and produces and sells Q_i units per year. In practice competition lessens the entrepreneur's profit, relative to monopoly profit, by κ_i.[1] The resulting contemporaneous profit flow is $\pi_i = (p_i - c_i)Q_i - F_i - \kappa_i$, and continues from time 0 for T_i years. Using discount rate ρ_i, a non-exiting entrepreneur's discounted profit is therefore

$$\Pi_i = \int_0^{T_i} e^{-\rho_i t}\pi_i dt - S_i \ = \pi_i \tilde{T}_i - S_i , \tag{1}$$

where $\tilde{T}_i = \frac{1}{\rho_i}(1 - e^{-\rho_i T_i})$.

Both product development and market outcomes are in part unpredictable. Their unpredictability is embodied by assuming that S_i and Q_i are independent random

[1] Our results extend to very general functional forms robust to alternative competitive models. The term κ_i in the profit equation can be replaced with a differentiable function $K_i(\kappa_i; p_i, c_i, Q_i, F_i)$, where κ_i is again an index of competition (reflecting the number and nature of competitors) and $\frac{\partial K_i}{\partial \kappa_i} > 0$. As long as increases in p_i or Q_i (c_i or F_i) yield smaller marginal competitive losses (gains) than the marginal benefits (losses) in the term $(p_i - c_i)Q_i - F_i$, our conclusions remain unaltered. This includes, for example, cases in which revenues, or positive profits, are divided by the index κ_i. Our conclusions extend even beyond this generalization as long as an appropriate weighted average of different entrepreneurs' competitive losses (gains) exceed the corresponding weighted average of benefits (losses) in the term $(p_i - c_i)Q_i - F_i$.

variables. S_i and Q_i have means μ_i and ν_i, and standard deviations ξ_i and ψ_i, respectively. The entrepreneur knows in advance the distributions of S_i and Q_i, but observes actual outcomes only after time 0 once sunk costs have been incurred and production has begun.

Before and after entry, alternative opportunities are available to the entrepreneur. Before entry, the best alternative life decision would yield the utility of a monetary payoff $\Omega_i > 0$. After entry, the entrepreneur can choose to exit when the entrepreneur has finally ascertained Q_i, and thereafter until T_i receive alternate revenue flow ω_i (or equivalent contributions to utility). After entry, therefore, production continues if and only if $\pi_i > \omega_i$.[2] Likewise, the entrepreneur either pays for the sunk costs of product and market development, or takes the outside opportunity, whichever yields greater expected utility.

Non-restrictive technical assumptions follow.

The model focuses on entrepreneurs for whom the price-cost margin is positive, $p_i - c_i > 0$, given their choice of output, since entrepreneurs with $p_i - c_i \leq 0$ would have $\Pi_i < 0$ and hence would never commercialize their ideas (and have no effect on the propositions derived from the model). It is assumed that $T_i, \rho_i, p_i, c_i, Q_i, F_i, S_i > 0$.

The probability density functions (p.d.f.s) of S_i and Q_i are $f_i^S(S_i)$ and $f_i^Q(Q_i)$ respectively. The p.d.f.s may be quite general, as they need only be bounded and satisfy the usual first and second order dominance conditions in appropriate parameters. S_i and

[2] Hopenhayn and Vereshchagina (forthcoming), among many others, nicely analyze the role of outside opportunities in entrepreneurs' entry decisions.

Q_i respectively are increasing in their means μ_i and ν_i, in the sense of first order stochastic dominance, and increasing in risk in their standard deviations ξ_i and ψ_i, in the sense of second order stochastic dominance. This allows for example for skew distributions of S_i and Q_i.[3]

The time when the entrepreneur has finally ascertained Q_i is denoted t_i^x, and is defined such that α_i ($0 < \alpha_i < 1$) is the fraction of the discounted profit flow up to this time. The alternate revenue flow ω_i (or equivalent contributions to utility) is defined such that it yields discounted value $\beta_i \Omega_i$ ($0 \le \beta_i \le 1 - \alpha_i$).[4,5] Entrepreneur *i*'s utility function is denoted as $U_i(\cdot)$, which is strictly increasing, differentiable, and bounded. The entrepreneur therefore enters if and only if

$$\begin{aligned} &\Pr\left[\pi_i > \omega_i\right] E\left[U_i(\Pi_i \mid \pi_i > \omega_i)\right] \\ &\quad + \Pr\left[\pi_i \le \omega_i\right] E\left[U_i\left(\alpha_i \pi_i \tilde{T}_i + \beta_i \Omega_i - S_i \mid \pi_i \le \omega_i\right)\right] > U_i(\Omega_i). \end{aligned} \tag{2}$$

The entrepreneur thus considers the opportunity for exit in determining whether to enter.

Outcomes in the population of entrepreneurs depend on the distribution of traits. Let $\theta_i = (p_i, c_i, F_i, \kappa_i, \mu_i, \nu_i, \xi_i, \psi_i, \rho_i, \tilde{T}_i, \alpha_i, \beta_i, \Omega_i, f_i^S(\cdot), f_i^Q(\cdot), U_i(\cdot))$ denote the parameter

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[3] A special case is $S_i = \mu_i + \xi_i \varepsilon_i^S$, $Q_i = \nu_i + \psi_i \varepsilon_i^Q$, where ε_i^S and ε_i^Q may be any continuous (possibly skew) independent random variables (whose distributions may differ for each *i*).

[4] It is in the entrepreneur's interest to choose the earliest possible exit time t_i^x (the smallest possible α_i) after S_i and Q_i are realized, but knowledge of the value of Q_i is typically substantially delayed after commercial production of a product begins.

[5] This implies $t_i^x = \dfrac{-\ln(1 - \alpha_i \rho_i \tilde{T}_i)}{\rho_i}$ with $0 < t_i^x < T_i$ and $\omega_i = \dfrac{\beta_i \Omega_i}{(1 - \alpha_i)\tilde{T}_i} > 0$.

vector for each entrepreneur.[6] The parameter space is assumed to be convex, and non-degenerate in that even given certain data-driven parameter values all entry and exit outcomes are possible.[7] The distributions of ρ_i, $\tilde{T}_i$, and α_i are assumed to yield a finite probability density function for t_i^x at all times $t_i^x \in (0, \max(T_i))$, where $\max(T_i)$ is the maximum possible value of $T_i = -\ln(1-\rho_i \tilde{T}_i)/\rho_i$. The parameter vector is assumed to be independently and identically distributed (i.i.d.) across entrepreneurs.[8] Parameters p_i, c_i, F_i, κ_i, μ_i, ν_i, ξ_i, and ψ_i are assumed to be distributed independently (or in practice they could be analyzed using proper controls in statistical analyses). Parameters ρ_i, $\tilde{T}_i$, and α_i are assumed to be (jointly) distributed independently of other parameters.

Implications

The model yields the following testable implications for entrepreneurs' decisions, labeled here as propositions P1-P9:

P1. Greater expected sunk cost is associated with reduced probability of entry.

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[6] The parameters $f_i^S(\cdot)$, $f_i^Q(\cdot)$, and $U_i(\cdot)$, which are functions, are written as a shorthand notation to mean one or more real-valued parameters yielding all possible variation in the functions. That is, write the general functions $f_{all}^S(\vec{\boldsymbol{f}}_i^S, \mu_i, \xi_i, z_i^1) = f_i^S(z_i^1)$, $f_{all}^Q(\vec{\boldsymbol{f}}_i^Q, \nu_i, \psi_i, z_i^2) = f_i^Q(z_i^2)$, and $U_{all}(\vec{\boldsymbol{u}}_i, z_i^3) = U_i(z_i^3)$, and in θ_i the terms $f_i^S(\cdot)$, $f_i^Q(\cdot)$, and $U_i(\cdot)$ are simplified notations for $\vec{\boldsymbol{f}}_i^S$, $\vec{\boldsymbol{f}}_i^Q$, and $\vec{\boldsymbol{u}}_i$ respectively. The number of elements in $\vec{\boldsymbol{f}}_i^S$, $\vec{\boldsymbol{f}}_i^Q$, and $\vec{\boldsymbol{u}}_i$ is assumed to be finite, and the general functions are assumed to be piecewise continuous in the elements of $\vec{\boldsymbol{f}}_i^S$, $\vec{\boldsymbol{f}}_i^Q$, and $\vec{\boldsymbol{u}}_i$.

[7] Specifically, the parameter vector has non-zero probability for the population of entrepreneurs in (and zero probability outside) a space that is assumed to be convex; to include for each p_i, c_i, F_i, κ_i, μ_i, ν_i, ξ_i, and ψ_i values θ_i that lead (for a nonzero fraction of entrepreneurs) to each possible outcome non-entry, entry followed by exit, and entry without exit; and to include more than one possible value for each parameter.

[8] Random sampling ensures that collected data are i.i.d.

P2. Greater manufacturing cost (fixed and per unit) is associated with reduced probability of entry.

P3. Greater competition is associated with reduced probability of entry.

P4. Greater price and expected output are associated with increased probability of entry.

P5. If entrepreneurs are risk-averse (risk-seeking), greater development uncertainty is associated with reduced (increased) probability of entry.

P6. If entrepreneurs are risk-averse, greater demand uncertainty may decrease or increase the probability of entry. If entrepreneurs are risk-seeking, greater demand uncertainty unambiguously increases the probability of entry.

P7. Greater expected sunk cost is associated with reduced probability and rate of exit.

P8. If entrepreneurs are risk-averse (risk-seeking), greater development uncertainty is associated with reduced (increased) probability and rate of exit.

P9. Greater manufacturing cost (fixed and per unit) and competition most likely have nonnegative (but near zero) effects on the probability and rate of exit, while greater price and expected output most likely have nonpositive (but near zero) effects on the probability and rate of exit.

Mathematical Derivations

The following analysis focuses on entrepreneurs for whom the price-cost margin is positive, $p_i - c_i > 0$, given their choice of output, since entrepreneurs with $p_i - c_i \le 0$ would have $\Pi_i < 0$ and hence would never commercialize their ideas (and have no effect on the hypotheses derived below).

The parameter space, θ, has dimensionality D equal to the number of elements in θ_i plus one. The one extra dimension, $\tau_i \in [0,1]$, is the realized quantile of Q_i in its distribution given ν_i and ψ_i. Each point (θ_i, τ_i) in the space corresponds to a particular entrepreneur *i*'s realization of the parameters. Each point has, by assumption, greater than zero probability density.[9] The parameter space is divided into contiguous subsets θ^j, $j = 1, \ldots, J$, in which E_i defined below has partial derivatives of constant sign (0 is combined with negative values) with respect to ψ_i, Ω_i, and the elements of $\vec{\boldsymbol{f}}_i^S$, $\vec{\boldsymbol{f}}_i^Q$, and $\vec{\boldsymbol{u}}_i$ (see footnote 6).

Dividing (at least one of) the subsets in half are two hypersurfaces, which are entry and exit bounds. The hypersurfaces bound regions of the parameter space in which the parameters imply it is optimal to enter versus not enter, and optimal to exit (assuming entry has occurred) versus not exit. The exit region is bounded by

$$X_i \equiv \pi_i - \omega_i = 0. \tag{3}$$

The entry region is bounded by (2) with the inequality replaced by an equality, which yields, after writing out the expected utilities and simplifying,

$$\begin{aligned} \mathrm{E}_i \equiv & \int_{S_i=0}^{\infty} \int_{Q_i=Q_i^x}^{\infty} U_i(\Pi_i) f_i^S(S_i) f_i^Q(Q_i) dQ_i dS_i + \\ & \int_{S_i=0}^{\infty} \int_{Q_i=0}^{Q_i^x} U_i(\alpha_i \pi_i \tilde{T}_i + \beta_i \Omega_i - S_i) f_i^S(S_i) f_i^Q(Q_i) dQ_i dS_i - \Omega_i = 0. \end{aligned} \tag{4}$$

In this entry bound, Q_i^x is the value of Q_i satisfying (3), i.e., the value at which exit just occurs, $Q_i^x = \dfrac{\omega_i + F_i + \kappa_i}{p_i - c_i}$.

[9] Discontinuities in the cumulative distribution function are allowed and correspond to infinite probability density.

Given specified values that an entrepreneur is known to have for *d* parameters, any of p_i, F_i, c_i, κ_i, μ_i, v_i, ξ_i, and ψ_i, one can ask how the entry and exit bounds would change if there were an exogenous increase in one of the *d* specified parameter values. Within θ^j the specified parameter values leave a $D-d$ dimensional subspace, with $D-d$ coordinate axes. The entry and exit bounds may shift, relative to the axes in the space $\mathbb{R}^{D-d}$ that contains θ^j, given the exogenous increase. The shift of one of these bounds may be analyzed in entirety using the implicit function theorem with $D-d+1$ variables. Or drawing a line parallel to any of the $D-d$ axes, the shift in the bound along this line can be analyzed using the implicit function theorem with two variables: the parameter whose axis the line parallels and the exogenously increased parameter (the other parameters being fixed according to where the line is drawn). Along *every* such line drawn parallel to an axis, whenever the entry bound intersects the line within θ^j, it will turn out that the entry region expands or stays the same, with expansion in some (positive measure of) cases. For the exit bound, it will turn out that when μ_i and ξ_i are exogenously increased, the region of exit remains the same, while exogenous increases in other parameters have more complex effects on the region of exit.

Figure 1 illustrates the shifts in the entry and exit bounds. The left panel pertains to exogenous increases in sunk cost parameters, μ_i and ξ_i. The right panel pertains to exogenous increases in other parameters. The horizontal axis in each panel, labeled ζ_i, determines the value of the exogenously changed parameter. The vertical axis, labeled γ_i, determines the value of the additional parameter. Better values of the parameters, in the sense of giving higher E_i, are plotted to the upper right (hence, e.g., $\zeta_i = -\mu_i$ in the first panel, not μ_i). The entrepreneur enters in the region denoted Entry, or exits supposing entry has occurred in the region denoted Exit. The margin between entry and non-entry is the solid boundary, and that between exit and non-exit is the dashed boundary.

The slopes of the bounds in Figure 1 are computed by differentiation of (3) and (4) using the implicit function theorem to reveal how parameters ζ_i affect the exit and entry bounds. Tedious differentiation, plus several mathematical tricks common in microeconomics, reveal the signs of the derivatives of E_i and X_i with respect to the model parameters.[10] The implicit function theorem then yields the slopes of the entry and exit curves in terms of the derivatives: $\left.\frac{\partial \gamma_i}{\partial \zeta_i}\right|_{E_i=0} = -\frac{\partial E_i}{\partial \zeta_i}\left(\frac{\partial E_i}{\partial \gamma_i}\right)^{-1}$ and $\left.\frac{\partial \gamma_i}{\partial \zeta_i}\right|_{X_i=0} = -\frac{\partial X_i}{\partial \zeta_i}\left(\frac{\partial X_i}{\partial \gamma_i}\right)^{-1}$. These derivatives yield the everywhere-negative (for some γ_i everywhere nonpositive) or everywhere-zero slopes depicted in Figure 1.[11] The exit bound in the right panel is drawn correctly for most vertical axis parameters, but is

[10] Leibnitz's rule is repeatedly required. The expected utility function must be integrated by parts and the definitions of first and second order dominance applied from expected utility theory.

[11] Some parameters are irrelevant to the analysis in some parts of the space. Specifically, the vertical axis parameter τ_i yields a perfectly vertical slope for the entry boundary; the vertical axis parameters μ_i and ξ_i yield a perfectly vertical slope for the exit boundary; entry or exit boundaries may be perfectly vertical in places if γ_i is a parameter in $\vec{\boldsymbol{f}}_i^S$, $\vec{\boldsymbol{f}}_i^Q$, and $\vec{\boldsymbol{u}}_i$ (see footnote 6); and when ζ_i and γ_i are (in either order) μ_i and ξ_i then the line drawn through the $D-d$ dimensional parameter subspace is parallel to the exit bound.

actually upward sloping for two or three of the many possible vertical axis parameters, α_i and β_i, as well as Ω_i in any subset θ^j in which $\frac{\partial E_i}{\partial \Omega_i} < 0$.

Since the entry region expands (or remains constant) in all directions γ_i as each ζ_i in Figure 1 increases to better values, better values of each ζ_i in Figure 1 imply greater probability of entry. (Note that the probability distribution across each θ^j is the same regardless of the value of ζ_i, since each ζ_i is independent of other model parameters.) This yields P1-P5.

The effects of demand uncertainty risk follow from the sign of

$$\begin{aligned}\frac{\partial E_i}{\partial \psi_i} &= (1-\alpha_i)\int_{S_i=0}^{\infty} U_i'(\omega_i \tilde{T}_i - S_i)(p_i - c_i)\tilde{T}_i \frac{\partial \tilde{F}_i^Q(Q_i^x)}{\partial \psi_i} f_i^S(S_i)dS_i \\ &+ \int_{S_i=0}^{\infty}\left(\int_{Q_i=0}^{Q_i^x} U_i''(\alpha_i \pi_i \tilde{T}_i + \beta_i \Omega_i - S_i)\left(\alpha_i (p_i - c_i)\tilde{T}_i\right)^2 \frac{\partial \tilde{F}_i^Q(Q_i)}{\partial \psi_i} dQ_i\right) f_i^S(S_i)dS_i \\ &+ \int_{S_i=0}^{\infty}\left(\int_{Q_i=Q_i^x}^{\infty} U_i''(\Pi_i)\left((p_i - c_i)\tilde{T}_i\right)^2 \frac{\partial \tilde{F}_i^Q(Q_i)}{\partial \psi_i} dQ_i\right) f_i^S(S_i)dS_i, \qquad (5)\end{aligned}$$

where $\tilde{F}_i^Q(Q_i)$ is the integrated cumulative density function for Q_i and satisfies $\frac{\partial \tilde{F}_i^Q(Q_i)}{\partial \psi_i} \geq 0$. As formidable as (5) appears, the tradeoffs are simply determined by signs of the integrands. The first term of (5) is nonnegative and reflects marginal utility gain associated with the entrepreneur's ability to exit, while the latter two terms in (5) have the same sign as $U_i''(\cdot)$ and reflect the traditional effects of risk on utility. Risk-averse entrepreneurs hence may have positive or negative $\frac{\partial E_i}{\partial \psi_i}$, while risk-seeking entrepreneurs unambiguously have $\frac{\partial E_i}{\partial \psi_i} > 0$. Only if $\frac{\partial E_i}{\partial \psi_i} < 0\ (> 0)$ on average in the population does the probability of entry fall (rise) with demand uncertainty. This yields P6.

The probability of exit conditional on entry can be computed as the probability of entry followed by exit divided by the probability of entry, yielding effects of parameters that result from shifts in entry and exit bounds. The probability of exit conditional on entry, given the value of any one parameter ζ_i, is

$$\Pr[i \text{ exits} \mid i \text{ enters}] = \frac{\Pr[\text{Entry\&Exit}]}{\Pr[\text{Entry}]}, \tag{6}$$

where Entry denotes the part of the parameter space where ζ_i holds and entry occurs, and $\text{Entry\&Exit}$ denotes the part of the parameter space where ζ_i holds, entry occurs, *and* exit occurs. This means that ζ_i affects the conditional exit probability, as the entry region and in some cases the exit region expand or contract with ζ_i.

Rate of exit is a function of time elapsed since entry. Exit, if it occurs, is at time t_i^x, so the distribution of t_i^x partly determines the function of time. For a randomly chosen individual, the Poisson rate at which time t_i^x arises is $f_{t_i^x}/(1-F_{t_i^x})$, where $f_{t_i^x}$ is the probability density function of t_i^x and $(1-F_{t_i^x})$ is the corresponding cumulative distribution function. Multiplying this Poisson rate for the arrival of time t_i^x by the probability of exit conditional on entry and on t_i^x, one obtains the Poisson rate $\lambda(t)$ at which exit occurs conditional on entry:

$$\lambda(t) = \frac{f_{t_i^x}(t)}{1-F_{t_i^x}(t)} \Pr[i \text{ exits} \mid i \text{ enters}, t_i^x = t] = \frac{f_{t_i^x}(t)}{1-F_{t_i^x}(t)} \frac{\Pr[\text{Entry\&Exit} \mid t_i^x = t]}{\Pr[\text{Entry} \mid t_i^x = t]}. \tag{7}$$

The term $\Pr[i \text{ exits} \,|\, i \text{ enters}, t_i^x = t]$ is not the same as (6), but can be analyzed by the same methods: below, only the subset of the parameter space corresponding to specific values of ρ_i, $\tilde{T}_i$, and α_i (which together determine t_i^x) is considered when analyzing (7) and then results are "integrated up" across these three dimensions, whereas all possible values of these parameters are considered when analyzing (6).

Implications for exit are straightforward in the cases $\zeta_i = \mu_i$ or ξ_i, for which $\frac{\partial X_i}{\partial \zeta_i} = 0$. The exit bound is flat, as illustrated in the left panel of Figure 2 for μ_i, with implications for the changing entry and exit probabilities. An increase of $\zeta_i = -\mu_i$ by $\Delta(-\mu_i)$ changes the relevant part of the parameter space from the left dashed vertical line to the right dashed vertical line. Along the two vertical lines the p.d.f. is identical since each ζ_i is independent of other model parameters. Before this shift the conditional probability of exit is (the p.d.f. integrated over line segment) AB divided by AC. After the shift the entry bound has fallen and increased the probabilities of entry and of entry *and* exit both by ΔPE. Hence the conditional probability of exit is much more, DE divided by DF. This yields P7-P8.

Implications are much more complex for the other ζ_i, which generally have $\frac{\partial X_i}{\partial \zeta_i} \neq 0$. Progress can be made on these cases if one is willing to make additional assumptions. One assumption is that cross-entrepreneur variability in α_i, β_i, and Ω_i (the latter only in θ^j having $\frac{\partial E_i}{\partial \Omega_i} < 0$) is sufficiently less important than cross-entrepreneur variability in other parameters. A second assumption is that entrepreneurs' probability distributions of parameters are not too skew in the direction of greater probability for better parameter values. The first assumption allows one to ignore the few vertical axis parameters with exit bounds that slope upward in the right panel of Figure 1. The second assumption allows one to assume that the probability density in the right panel is nonincreasing in the vertical direction.

Using these additional assumptions, the exit bound shifts downward with ζ_i, as illustrated for p_i in the right panel of Figure 2, so the reduction ΔPE in the entry *and* exit probability is accompanied by a reduction ΔPX in the exit probability. This compensating effect yields a net effect on the conditional probability of exit that, without the second additional assumption, could be positive or negative depending on the particular p.d.f. and on the precise shapes of the entry and exit bounds. With the second assumption one tends to observe a decrease or no change in the conditional probability of exit, rather than a increase: the numerator in (6) or (7) stays about the same while the denominator shrinks since $\mathrm{JK} \cong \mathrm{MN}$; this tendency is readily apparent with a uniform p.d.f. and would be reinforced by typical skew distributions of entrepreneur traits in which the best traits are rare. This is only a tendency because it depends on the relative movements of the entry and exit bounds. (The special case of ψ_i would require further assumptions and is not addressed here.) This yields P9.

References

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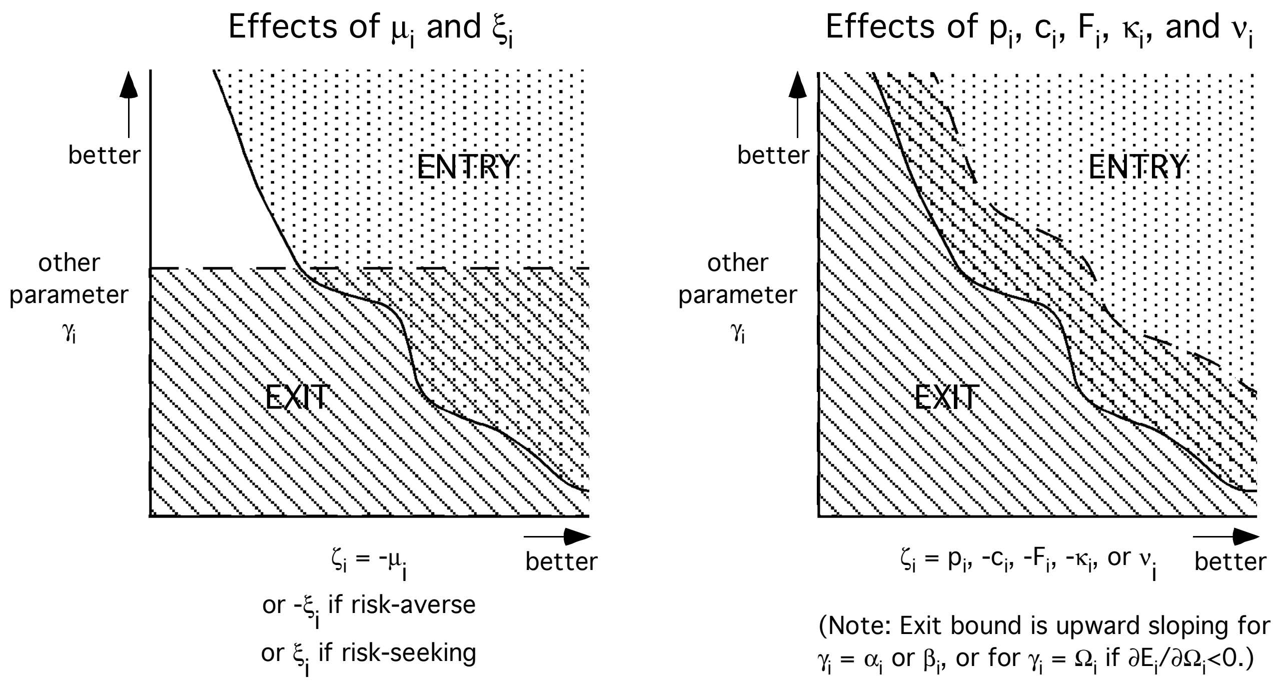

Figure 1. Effects of a Parameter ζ_i on Entry and Exit

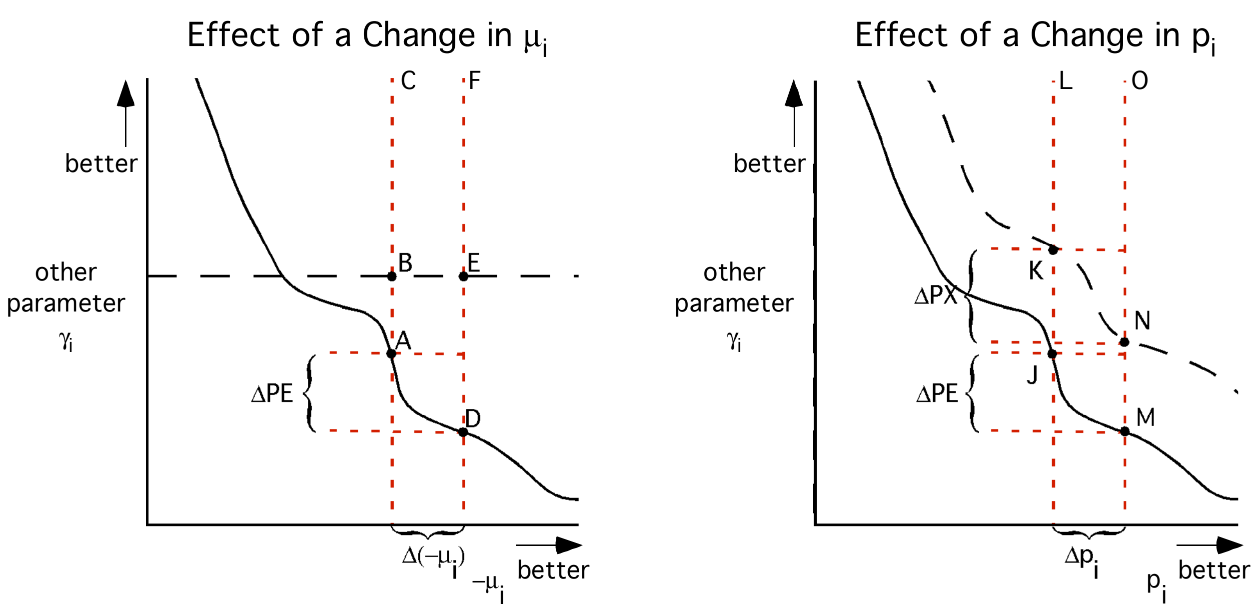

Figure 2. How a Parameter Affects the Conditional Exit Probability