Facilitating Academic Entrepreneurship*

Richard Jensen
The University of Notre Dame

Marie Thursby
The Georgia Institute of Technology and NBER

Huyen Pham
Analysis Group

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Abstract

Research universities continually struggle with issues related to commercialization of faculty research. Increasingly, they must hire and support faculty conducting cutting-edge science, but also facilitate commercialization of their research. Many universities provide resources to faculty through venture labs and/or entrepreneurial sabbaticals. The topic has been front and center for decades, but little systematic is known about whether faculty members take advantage of these mechanisms.

We use a life-cycle model of faculty research to examine the extent to which a faculty researcher engages in entrepreneurial activity. In each period, she allocates her time among applied and basic research, entrepreneurial activity, and leisure. Entrepreneurial effort is a possibility only if she has an innovative idea, the probability of which is a function of her stocks of research and entrepreneurial knowledge. If she has an idea, she may ignore it, pursue it within the consulting limits of her contract, or take an entrepreneurial sabbatical. In each period, we compute the probability of an idea, the probabilities she is a full time faculty member, a hybrid professor, or a full time entrepreneur, and the optimal time allocations and knowledge stocks.

Without substantial income supplements, she is unlikely to ever take a sabbatical leave. Even when she does, it is late in her career. Mechanisms designed to make her entrepreneurial effort more productive reduce the likelihood that she will take sabbaticals, but increase the likelihood of hybrid behavior. Our model also highlights the importance of having an idea and lends theoretical justification for the low rates of participation in commercial pursuits found in prior empirical work.

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1 Introduction

Research universities continually struggle with issues related to academic entrepreneurship—faculty starting companies to commercialize ideas based on their research. Increasingly, the so-called "ivory tower" must hire and support faculty conducting cutting edge science and also facilitate commercialization of their research. These dual demands are not new. In fact, incubators designed to provide faculty resources for commercialization have been around for more than four decades. Nonetheless, the fact that the commercialization process is anything but seamless keeps the topic front and center (Shane 2004; Higgins et al. 2010). For example, new approaches to promoting academic entrepreneurship were the focus of the 2012 "Presidents-Investors Summit" of university presidents, government officials, and venture capitalists. One of their major recommendations was to allow sabbatical leaves for faculty interested in entrepreneurship – a policy apparently allowed in only half of the universities participating (Blumenstyk 2012).

Moreover, some universities have begun to alter their reward and incentive structures for faculty in an attempt to boost entrepreneurship and technology transfer. In addition to allowing sabbatical leaves for entrepreneurship, Northwestern's McCormick School of Engineering and Applied Science allows faculty to earn salary up to 25 percent above their standard academic salary while on sabbatical.[1] A growing number of universities, beginning with Texas A&M in 2006, now explicitly include patents and various measures of technology commercialization in their criteria for promotion and tenure (Stevens et al. 2011). Most recently, the University of Arizona adopted new criteria that explicitly place the same emphasis on "commercialization activities and patents" as on "original research contributions in peer-reviewed publications."[2]

However, neither how faculty members will respond to such sabbaticals nor their impact on the university research enterprise is known. If faculty leave the university to pursue commercialization, they may abandon or at least reduce their research efforts. Existing evidence on the research productivity of commercially engaged faculty is mixed, with some studies showing diversion of effort (Toole and Czarnitzki 2010).and others pointing to higher research productivity among those commercially involved (Azoulay et al. 2009; Thursby and Thursby 2010). In terms of faculty initiation of start-ups under alternative regimes, the National Academies report on *Managing University Intellectual Property in the Public Interest* reports that sufficient evidence of participation is simply too limited. While we have evidence suggesting why some universities generate more startups than others, it is at the university rather than faculty level (Digregoio and Shane 2003).

We construct a life cycle model of faculty research which allows us to examine the extent to which a faculty researcher engages in entrepreneurial activity when it is possible to take sabbatical leaves to

[1] See http://www.mccormick.northwestern.edu/docs/nu-only/mcc-faculty-leave-policy.pdf.

[2] See http://www.uanews.org/story/ua-adds-tech-transfer-to-promotion-tenure-criteria.

commercialize ideas based on her research. In each period, the researcher decides the allocation of her time among applied and basic research, entrepreneurial activity, and leisure. Entrepreneurial effort is relevant only if she identifies an entrepreneurial opportunity which we refer to as an innovative idea. The probability she has such an idea is a function of her stocks of research and entrepreneurial knowledge. Thus, we condition entrepreneurial decisions, not only on entrepreneurial or market knowledge, as in Shane (2000), but also on knowledge from prior research, as in Zucker et al. (1998). Conditional on having an innovative idea, she may ignore it, pursue it within the consulting limits of her contract, or take an entrepreneurial sabbatical. We model faculty utility as a function of applied and basic effort, salary, and expected profit when she is entrepreneurial, and production of applied, basic, and entrpreneurial knowledge is probabilistic. In each period, we find the probability that a researcher has an idea, the probabilities she is a full time faculty member, a hybrid professor, or a full time entrepreneur, as well as the optimal effort levels and stocks of knowledge.

The results are striking. We find that without substantial supplements to her income, she is unlikely to ever take a sabbatical leave. When she does, it is well into her career. We also examine the impact of mechanisms, such as workshops, venture labs, or technology parks, designed to make her entrepreneurial effort more productive. For the parameter values we consider, such efforts reduce the likelihood that she will take sabbaticals but increase the likelihood of hybrid behavior.

Our model also highlights the importance of innovative ideas as distinct from entrepreneurial skills. Throughout the scenarios we examine, the changes which have the greatest impact are those that improve the faculty member's ability to convert her research into an innovative idea. In this regard, our model contributes to the literature emphasizing the importance of ideas, themselves, as distinct from innovative effort, in R&D outcomes (O'Donoghue, Scotchmer and Thisse 1998, Erkal and Scotchmer 2009, and Banal-Estanol and Macho-Stadler 2010). In contrast to Erkal and Scotchmer (2009) who assume ideas arrive at a predetermined rate or Banal-Estanol and Macho-Stadler (2009) who assume ideas depend on period effort, we treat faculty ideas are functions of the stocks of knowledge. In contrast to Shane (2000)'s emphasis on one's stock of market knowledge affecting the type of idea one exploits, we identify the probability of having an idea based on research and entrepreneurial knowledge stocks.

Our work also contributes to the emerging theoretical literature on academic R&D choices when both industrial and academic activity is possible (Jensen and Pham 2012, Agarwal and Ohyama 2012, Banal-Estanol and Macho-Stadler 2009, Lacetera 2009, Thursby, Thursby, and Gupta-Muhkerjee 2007).

2 Model

We construct a life cycle model of faculty research which allows us to examine the extent to which a faculty researcher engages in entrepreneurial activity during her career. At each date $t = 1, ..., T$, she allocates her time among applied research, a_t, basic research, b_t, entrepreneurial effort, e_t, and leisure, l_t, where we index time so that $a_t + b_t + l_t + e_t = 1$. We define applied research as effort intended to increase the stock of patentable knowledge, A_t and basic research as effort intended to increase the stock of scientific knowledge, B_t. Entrepreneurial effort is activity in a startup company devoted to commercializing an innovative idea. The idea could come from past research success (either basic or applied) or from prior entrepreneurial experience. Successful entrepreneurial effort increases the stock of entrepreneurial knowledge, E_t.

In any period, the probability that a researcher has an innovative idea is $P_I(A_t, B_t, E_t)$, which is increasing and jointly concave in the three knowledge stocks. For our simulation, we define this probability as

$$P_I = \frac{\nu_A A + \nu_B B + \nu_E E}{1 + \nu_A A + \nu_B B + \nu_E E} \tag{1}$$

where ν_A, ν_B, and ν_E are non-negative constants that correspond to the effects of the stocks of applied and basic research, and entrepreneurial experience, respectively. The terms ν_A and ν_B reflect the researcher's ability to translate her patentable and scientific knowledge into an innovative idea, while ν_E reflects her ability to generate innovative ideas from her entrepreneurial success.

Suppose a faculty member has an innovative idea. Under the conventional university policy of allowing consulting up to a limit, $\bar{e} < 1$, she can pursue the idea and also conduct research as long as $e_t \leq \bar{e}$. Above $\bar{e}$ she needs to take an entrepreneurial sabbatical, in which case we assume she takes a holiday from research and $e_t = 1 - l_t$. Finally, if she chooses not to pursue the idea, then $e_t = 0$ and she spends time only on research efforts and leisure. We refer to these three cases as *hybrid, exit, and professor* outcomes.

Throughout we abstract from licensing alternatives as the inclusive would only complicate the analysis without significant insights.

2.1 Preferences

Faculty utility, Ψ, has both non-pecuniary and pecuniary elements. While this is true, in general, it is particularly important in modeling academic entrepreneurship, as research and commercial goals of faculty can lead to conflicting incentives (Lacetera 2009).

One of the well-known non-pecuniary aspects of faculty research is the ability to engage in problem solving, which we represent as time spent in research (Hagstrom 1965, Jensen and Thursby 2004, Agarwal and Ohyama 2012). That is, we explicitly assume that time spent in research, or research "effort," is a "good" for our faculty researcher. We also assume that time spent in entrepreneurship, or entrepreneurial effort, is also a good that provides non-pecuniary benefits. These benefits may be associated with company ownership, as in Blanchflower and Oswald (1998) and Hamilton (2000), or in an academic setting, it is natural to think of faculty members deriving utility from seeing the practical realization of their research (Thursby and Thursby 2009). Hereafter, we refer to time spent in research or entrepreneurial activity as "effort" for expositional ease, although we emphasize that these activities are goods to the researcher, and so do not involve an effort cost, as is common in traditional models of labor. Finally, as is standard, utility is also derived from time spent in leisure.

Thus, in each period, non-pecuniary utility is given by $U = U(a_t, b_t, e_t, l_t)$ which we assume takes a Cobb-Douglas form

$$U(a_t, b_t, e_t, l_t) = a^{\gamma_a} b^{\gamma_b} + e^{\gamma_e} + l^{1-\gamma_a-\gamma_b}$$

where γ_a, γ_b, and γ_e are positive constants such that $\gamma_a + \gamma_b + \gamma_e < 1$. This form allows us to use γ_a ,γ_b, and γ_e as measures of the researcher's preference for applied, basic, entrepreneurial activities.

The pecuniary component of utility is given by her income, Y_t. As an academic, she earns her current academic salary, $S(A_t, B_t)$, which is a function of the stocks of applied and basic knowledge. We also assume her university salary is Cobb-Douglas in both knowledge stocks, $S(A, B) = A^s B^{1-s}$, where $s \in (0, 1)$ is a constant. Generally we expect her stock of scientific knowledge to have a greater impact on her salary, $s < 1/2$.

If she is an entrepreneur full time in period t, she earns a share α of the expected profit $\mathbf{E}(\pi_t)$ from the start-up in that period. She may also receive a portion, ϵ, of her academic salary $S(A_t, B_t)$ as a sabbatical payment to engage in entrepreneurship or as part of an entrepreneurial grant. If she chooses a hybrid career in period t, she receives her full academic salary $S(A_t, B_t)$ from the univerisity and her share of the firm's profit $\alpha\mathbf{E}(\pi_t)$.

2.2 Production

In period t, the allocation of time between applied and basic research and the current knowledge stocks determine the probability of success in each research program. These probabilistic production functions for knowledge are the transition probabilities between current state (A, B, E) and potential future states (A', B', E') where $A' \geqslant A$, $B' \geqslant B$, and $E' \geqslant E$. Thus, for given efforts and knowledge stocks (a, b, e, A, B, E), denote the probability that the state transitions to (A',B',E') by $P(A',B',E'|a,b,e,A,B,E)$. Notice this form allows spillovers from basic to applied research and vice versa, as in Pasteur's Quadrant (Mansfield 1995 and Stokes 1997). We assume these are increasing in the efforts and knowledge stocks, and strictly quasi-concave in (a,b,e).

2.2.1 Research Stocks of Knowledge

For tractability, we assume that the state space for each knowledge stock is countably finite, so $A,B,E = 1,2,...M$. We also assume the transition probabilities for each type of knowledge stock are independent and take the forms

$$P(A+1|a,A,B,E) = \frac{(\delta_a + \Delta_{AA}A + \Delta_{BA}B + \Delta_{EA}E)a}{1+(\delta_a + \Delta_{AA} + \Delta_{BA}B + \Delta_{EA}E)a} \tag{2a}$$

and

$$P(B+1|b,A,B,E) = \frac{(\delta_b + \Delta_{AB}A + \Delta_{BB}B + \Delta_{EB}E)b}{1+(\delta_b + \Delta_{AB}A + \Delta_{BB}B + \Delta_{EB}E)b} \tag{2b}$$

where δ_a , δ_b, Δ_{AA} , Δ_{BB} are positive constants and Δ_{IJ} $I \neq J$, for $I,J = A,B,E$, are non-negative constants. The parameter δ_i measures the direct effect of time in applied and basic research on a one-step increase in patentable and scientific knowledge, respectively, while Δ_{IJ} indexes the effects of the stocks of knowledge. Thus current research effort of either type has a direct effect only on the probability of success for its own stock of knowledge. However, past research efforts can improve the transition probabilities for both types of research knowledge through the stocks. Past research of either type increases both transition probabilities through past successes if $\Delta_{IJ} > 0$ for $I \neq J$, which allows for Pasteur's Quadrant-type spillovers among types of research. Generally we expect the own effect to be greater, $\Delta_{II} > \Delta_{IJ}$ where $I \neq J$. We also allow for the possibility that past entrepreneurial effort affects the probability of success in research to the extent that it increased the stock of entrepreneurial knowledge. For much of our analysis, however, we will consider cases where $\Delta_{EB} = \Delta_{EA} = 0$.

2.2.2 Entrepreneurial Knowledge Stock

The transition probability for entrepreneurial knowledge stock assumes the form

$$P(E+1|e,A,B,E,k) = \frac{(\Delta_{AE}A + \Delta_{BE}B + \Delta_{EE}E + \Delta_\kappa \kappa)e}{1+(\Delta_{AE}A + \Delta_{BE}B + \Delta_{EE}E + \Delta_\kappa \kappa)e} \tag{3}$$

where Δ_{AE}, Δ_{BE}, Δ_{EE}, and Δ_κ are positive constants. In our model, the expression in (3) also denotes the probability that the researcher successfully commercializes an innovative idea in a start-up. This probability is an increasing function of the current entrepreneurial effort, current stocks of research and entrepreneurial knowledge, and the level of available capital. In contrast to (2a) and (2b), entrepreneurial effort has no direct effect on this probability of success in the absence of capital and positive stocks of knowledge. The parameter Δ_{AE} indexes the effect of the current stock of patentable knowledge on the probability of success, while the parameter Δ_{BE} indexes the effect the current stock of scientific knowledge on this probability. This specification reflects the fact that the researcher's scientific expertise is often critical for commercial success (Jensen and Thursby 2001). The parameter Δ_{EE} indicates that serial entrepreneurs possess valuable managerial and business knowledge that they have acquired from past ventures. These experiences may facilitate the success of future start-ups (Gompers et al. 2010). Finally, we assume that financial capital κ has a positive effect Δ_{κ} on the likelihood of entrepreneurial success as documented in the literature (Evans and Jovanovic 1989, Holtz-Eakin, Joulfaian, and Rosen 1994, Blanchflower and Oswald 1990, Lerner 1999, Hellman and Puri 2000, Audretsch et al. 2002).

2.2.3 Expected Profit

Conditional on having an innovative idea, the expected profit that the start-up can generate is the product of the probability that the venture succeeds in (3) and the intrinsic value of the idea net of the initial capital κ. We assume that the idea's intrinsic value depends on the researcher's stocks of applied and basic research and her entrepreneurial expertise, or

$$\pi(A, B, E) = A^{\phi_A} B^{\phi_B} E^{\phi_E} - \kappa. \tag{4}$$

Thus the expected profit $\mathrm{E}(\pi_t)$ at time t is computed as

$$E(\pi_t) = P(E_t + 1 | e_t, A_t, B_t, E_t, \kappa) \times \pi(A_t, B_t, E_t). \tag{5}$$

2.3 Value Functions

We consider a problem of T periods, where the faculty retires at T. For notational convenience, set $\theta_t = (a_t, b_t, e_t, l_t)$.Then for any time period t where $t \neq T$, with probability $(1 - P_I)$, she has no innovative ideas and her value function is

$$\begin{aligned} V_{t,NoInnovation}(A_t, B_t, E_t) = \max_{a_t, b_t} \{ & U(a_t, b_t, l_t) + S(A_t, B_t) \\ & + \beta \sum^{A_{t+1}} \sum^{B_{t+1}} P(A_{t+1}, B_{t+1} | \theta_t) V_{t+1}(A_{t+1}, B_{t+1}, E_t) \} \end{aligned} \tag{6}$$

where the researcher chooses time spent in research efforts and leisure but does not engage in entrepreneurial activity. That is, $e_t = 0$ in θ_t and the stock of entrepreneurial knowledge E_t does not change in the next period. Her sole income source is the academic salary $S(A_t, B_t)$ which is a function of her stocks of research knowledge.

With probability, P_I, she has an innovative idea and her value function is defined by

$$
\begin{aligned}
V_{t,Innovation}(A_t, B_t, E_t) = \max_{a_t, b_t, e_t} & \{\max\{V_{t_P}, V_{t_E}, V_{t_{PE}}\} \\
& + \beta \sum^{A_{t+1}} \sum^{B_{t+1}} \sum^{E_{t+1}} P(A_{t+1}, B_{t+1}, E_{t+1}|\theta_t) V_{t+1}(A_{t+1}, B_{t+1}, E_{t+1})\},
\end{aligned} \tag{7}
$$

subject to $a_t \geq 0, b_t \geq 0, e_t \geq 0$, $l_t = 1 - a_t - b_t - e_t$, and $V_{t_P}, V_{t_E}, V_{t_{PE}}$ are the value functions conditional on the presence of an innovation if the researcher chooses to be a professor, an entrepreneur, or both.

2.3.1 Conditional Value Function of the Professor Option

If the researcher specializes in research activities, so that $e_t = 0$, the value function is identical to the one specified in (6).

$$
V_{t_P}(A_t, B_t, E_t) = \max_{a_t, b_t}\{U(a_t, b_t, l_t) + S(A_t, B_t) + \beta \sum^{A_{t+1}} \sum^{B_{t+1}} P(A_{t+1}, B_{t+1}|\theta_t) V_{t+1}(A_{t+1}, B_{t+1}, E_t)\}, \tag{8}
$$

Her utility therefore depends on time spent in applied and basic research, and leisure and her sole source of income is her university salary $S(A_t, B_t)$.

2.3.2 Conditional Value Function of the Sabbatical Option

If the researcher takes an entrepreneurial sabbatical, then the value function is given by

$$
\begin{aligned}
V_{t_E}(A_t, B_t, E_t) = \max_{e_t} & \{U(a_t, b_t, e_t, l_t) + \epsilon S(A_t, B_t) + \alpha \mathbf{E}(\pi_t) \\
& + \beta \sum^{E_{t+1}} P(A_{t+1}, B_{t+1}, E_{t+1}|\theta_t) V_{t+1}(A_{t+1}, B_{t+1}, E_{t+1})\}, \\
& \text{subject to } \overline{e} < e_t \leq 1
\end{aligned} \tag{9}
$$

In this case, the time she chooses to spend in entrepreneurial activity e_t exceeds $\overline{e}$ and $a_t = b_t = 0$. She may receive a portion of her academic salary, $\epsilon S(A_t, B_t)$ according to her university's sabbatical policy, where $\epsilon \in [0, 1)$. She also receives a portion of the firm's profit $\alpha \mathbf{E}(\pi_t)$ as a second source of income.

2.3.3 Conditional Value Function of the Hybrid Option

The main difference between the hybrid case and the entrepreneurial sabbatical is that in the hybrid, she receives the full amount of her academic salary $S(A_t, B_t)$. Thus the value function is

$$V_{t_{PE}}(A_t, B_t, E_t) = \max_{a_t, b_t, e_t} \{U(a_t, b_t, e_t, l_t) + S(A_t, B_t) + \alpha \mathbf{E}(\pi_t) \tag{10}$$
$$+ \beta \sum^{A_{t+1}} \sum^{B_{t+1}} \sum^{E_{t+1}} P(A_{t+1}, B_{t+1}, E_{t+1} | \theta_t) V_{t+1}(A_{t+1}, B_{t+1}, E_{t+1})\},$$
$$\text{subject to } 0 < e_t \leq \overline{e}$$

3 Simulation

We simulate a researcher's life over $T = 30$ time periods using the equilibrium solution obtained in the model. The equilibrium solution consists of two sets of functions: $a^*_{t,NoInnovativeIdea}(A, B, E)$, $b^*_{t,NoInnovativeIdea}(A, B, E)$, and $e^*_{t,NoInnovativeIdea}(A, B, E)$ and $a^*_{t,InnovativeIdea}(A, B, E)$, $b^*_{t,InnovatioveIdea}(A, B, E)$, and $e^*_{t,InnovativeIdea}(A, B, E)$ that yield the optimal value functions specified in (6) and (7). In each period, we first apply the current knowledge stocks A_t, B_t, and E_t to (1) to compute the probability of an innovative idea, P_I, and make a draw to determine the existence of such an idea. Depending on the realization of an innovative idea, we then substitute the corresponding optimal applied, basic, and entrepreneurial efforts and the current knowledge stocks A_t, B_t, and E_t into the transition functions $(2a), (2b)$, and (3) in order to compute the probability of each set of future stocks $(A_{t+1}, B_{t+1}, E_{t+1})$. We next make a second draw to determine the realization of $(A_{t+1}, B_{t+1}, E_{t+1})$ in period $t + 1$. With the realized set $(A_{t+1}, B_{t+1}, E_{t+1})$ and $t + 1$, we can identify applied, basic, and entrepreneurial efforts from the equilibrium solutions for period $t + 1$.

In period $t = 1$, we assume that the researcher starts at the minimum levels of both applied, basic, and entrepreneurial knowledge $(1, 1, 1)$ and apply the preceding steps to find the time paths of $a^*_t(A, B, E)$, $b^*_t(A, B, E)$, and $e^*_t(A, B, E)$ until the last period T. Our results also include the paths of applied, basic, and entrepreneurial knowledge and salary income. In order to mitigate the effects of extreme draws and obtain results that closely approximate the equilibrium paths, we run the simulation 500 times for each variable and report the time paths of the *averages.* Details are presented in the appendix.

Throughout, we assume indifference among different types of efforts ($\gamma_a = \gamma_b = \gamma_e$) and equal productivity in applied and basic research effort ($\delta_a = \delta_b = 5$ and $\Delta_{AA} = \Delta_{BB} = 1$). In addition, we allow for spillovers between the two stocks of knowledge from research ($\Delta_{AB} = \Delta_{BA} = .5$) to reflect the wealth of research in Pasteur's Quadrant. However, we assume that basic knowledge has a greater influence on the salary and less on the entrepreneurial profit than applied knowledge ($0.5 > s$, $\phi_B < \phi_A$).

To ensure that entrepreneurial exit is feasible, we assume positive values for the parameters in (3) and (1). The baseline value of all parameters in the probability of having an innovative idea (ν_A, ν_B, and ν_E) is .1, and the baseline value of all parameters in the probability of a successful venture ($\Delta_{AE}, \Delta_{BE}, \Delta_{EE}$, and Δ_κ) is 1 so that there is a positive probability of entrepreneurial success given any positive e_t. These two assumptions put entrepreneurial experience and research on an equal footing in generating ideas with commercial potential as well as entrepreneurial success. However, we abstract from any potential impact of successful entrepreneurship on the research production functions ($\Delta_{EA} = \Delta_{EB} = 0$) until Section 6.

4 Entrepreneurial Sabbatical Policies

In practice, some universities provide paid entrepreneurial sabbatical leaves while others allow only unpaid leaves of absence. For those providing salary, the percent of the faculty member's academic salary paid during the sabbatical typically depends on the amount of time the faculty member is absent from the university. If she is absent for a full year, a common salary cap is fifty percent salary. In most cases, universities allow faculty to add outside stipends or salary from their entrepreneurial pursuits, although they may place a cap on such supplements. For example, Northwestern pays faculty fifty percent of their salary for a one year leave and allows the faculty member to add outside supplements up to a cap of 1.25 of her academic salary. Thus we consider entrepreneurial participation for several values of epsilon.

4.1 Half Salary

Figure 1a shows faculty participation in entrepreneurial pursuits when $\epsilon = .5$. Because entrepreneurial activity is relevant only when a faculty member has an innovative idea, the figure shows the probability that she has an innovative idea as well as the probability of hybrid, exit, and professor outcomes. Given the minimal initial stocks of knowledge, the probability of an innovative idea is .quite small initially and increases until the end of the career when the average probability is approxminately .2. Two results are striking. First, the faculty member *never* takes an entrepreneurial sabbatical! Contingent on having an innovative idea, she may spend time developing it in a company, but her entrepreneurial effort is part time. Second, once she has spent 10 years on the faculty, whenever she has an innovative idea, she will try develop it while maintaining her full time academic position. Thus she continues to conduct research and the probability of a hybrid situation tracks the probability of having such an idea.

To examine whether these results are an artifact of the parameters chosen, we simulated the results for a variety of assumptions on other parameters. Regardless of the values chosen, when $\epsilon = .5$, entrepreneurial sabbaticals are never taken. For example, Figure 1b shows the results when all parameter values are as specified above, except for $\nu_E = .9$ and $\Delta_{EE} = \Delta_\kappa = 5$ so that entrepreneurial endeavors should be extraordinarily successful, *ceteris paribus*. The results are similar to those in 1a. The hybrid outcome occurs with positive probability almost immediately, the point at which she almost surely tries to develop any innovative idea is around 10 years into her career, and the probability of exit is zero throughout her career. The major difference in these two cases is in the probability of an innovative idea. With the baseline values of ν_E, Δ_{EE}, and Δ_κ the average probability of an innovative idea ranges from .002 to .2, while it ranges from .009 to .3 with the higher values of ν_E, Δ_{EE}, and Δ_κ.

We also considered the Northwestern policy of allowing supplemental income on top of half salary during a sabbatical. Figure 1c gives the results where $\epsilon = 1.25$, so that she can earn a twenty five percent premium over her normal academic salary by taking the sabbatical. All other parameters are assumed to be their baseline values. Not surprisingly, we see a positive response to entrepreneurial sabbaticals, but, again the results are striking. There is a positive probability of entrepreneurial exit only after 10 years into her career, and she is almost sure to exit whenever she has an innovative idea only 24 years into her career.

4.2 Minimal Salary for an "Effective" Sabbatical

Clearly, if an entrepreneurial sabbatical is to have any real impact, university managers need to consider the portion of normal salary needed for faculty to "take" a sabbatical! Thus we considered values of ϵ from between .5 and 1 with the benchmark parameters as well as others. While we found some entrepreneurial exit for $\epsilon = .8$, the minimum value of epsilon for which we found exit with the benchmark parameter values in Section 3 was $\epsilon = .9$. Thus we adopt this case as a benchmark for an effective sabbatical policy, where we define an "effective" policy that induces faculty exit for development of their ideas. The benchmark should be thought of in terms of faculty having minimal stocks and entrepreneurial skills, so that one could justify the need for university policies to encourage entrepreneurship in situations where faculty effort is critical for commercial development.

Figure 2 shows, not only the probabilities, but also the equilibrium effort levels and resulting stocks of knowledge for this benchmark. It is useful to consider all three graphs since the equilibrium effort levels determine the stocks which, in turn, determine the equilibrium probabilities.

The levels of applied and basic research in this example are relatively constant until the second half of the career cycle. At that point they decline since the marginal returns to doing applied and basic research decline as the faculty member accumulates higher knowledge stocks. This decline is consistent with other life cycle models of research effort (Levin and Stephan 1991; Thursby et al. 2007; Jensen and Pham 2012). Accordingly, the stocks of applied and basic knowledge rise at a decreasing rate over time.

Entrepreneurial effort begins almost immediately, but on a scale low enough to remain as full time faculty. During the second half of her career, the faculty member starts to show entrepreneurial exit, as well as increased in time spent in leisure. The virtual equality of the basic and applied efforts follows from our assumptions on preferences and productivity. Notice that the probability of each outcome is qualitatively similar to those discussed earlier (Figure 1).That is, the probability of hybrid behavior rises until it tracks the probability of an innovative idea 10 years into the career. It is not until after 15 years that entrepreneurial exit occurs. Moreover, the magnitudes are quite small and it is the probability of an innovative idea that constrains limits entrepreneurial activity.

5 The Productivity of Entrepreneurial Effort

In examining academics as entrepreneurs, our interest is in commercialization of their research as opposed to generic entrepreneurship. Thus, it is human capital associated with prior research which is critical for further development and the basis for universities to allow hybrid activity as well as university-supported sabbaticals. Many universities provide other forms of support, such as workshops on entrepreneurship and venture labs within the university. In fact, universities adopting expedited licenses for faculty startups require faculty to attend such workshops prior to license. In some cases, universities provide financial capital or facilitate faculty attempts to attract financial capital. Many also house faculty startups in institutions such as incubators, research corporations, and technology enterprise parks. Such institutions target several dimensions of academic entrepreneurship effort– facilitating research-related entrepreneurial activity, improving entrepreneurial skills, as well as relaxing the capital constraints facing the faculty entrepreneur.

In this section, we consider the impact of such support on the likelihood of entrepreneurial activity, as well as effort levels and the stocks of knowledge. All of these mechanisms are designed to improve the productivity of entrepreneurial effort, however, it is useful to distinguish between those aimed at improving the contribution of the faculty member's knowledge stocks and those which increase the productivity of financial capital. As we shall see, mechanisms designed to improve the impact of prior research, all else equal, have a more dramatic effect on entrepreneurial success than those to augment financial capital, essentially because they interact with the endogenously determined stocks. We also see that, compared to the benchmark, such measures tend of promote faculty retention for research, i.e., hybrid activity.

5.1 Stocks of Research Knowledge (Δ_{AE}, Δ_{BE})

Figures 3 and 4 show the results of an increase in Δ_{AE} and Δ_{BE}, respectively. In Figure 3, all parameters are as in the benchmark except for $\Delta_{AE} = 5$, and in Figure 4, all parameters are as in the benchmark except for $\Delta_{BE} = 5$.

In each case, although there is a five-fold increase in the relevant parameter (Δ_{AE} and Δ_{BE}, respectively), the probability of having an innovative idea remains the same as in the benchmark throughout the faculty member's career. Contingent on having such an idea, the probabilities of hybrid and exit are virtually the same as in the benchmark until almost 20 years into the career, when the hybrid increases and exit decreases!

This result is completely counter to the fears of critics who fear the destruction of the research university when universities invest in entrepreneurship. It is, of course, completel intuitive when one thinks about the effect of increases in productivity. Whenever Δ_{AE} or Δ_{BE} increase, the effectiveness of entrepreneurial effort, e, increases because the marginal productivity of the respective knowledge stock increases. Thus, she can earn the same expected profit with less entrepreneurial effort than she can when her research knowledge contributes less to the success of the venture. Thus, all else equal, there will be more hybrid cases in equilibrium.

Importantly, the fact that she is more likely to remain in the university as a hybrid professor means that the stock of future research is unlikely to suffer, and in the cases we consider her stock increases slightly relative to the benchmark. Also notice that the stock of entrepreneurial knowledge increases noticeably over the benchmark.

5.2 Financial capital

Figure 5 shows the probabilities, efforts, and stocks when all parameters are as in the benchmark except for $\Delta_{\kappa} = 10$. This parameter change increases the effectiveness of financial capital, κ, which could occur for a variety of reasons, most notably the provision of complementary assets in a university incubator. Notice that we see the same patterns as in Figures 3 and 4. The main difference from those in the previous section is that κ is a lump-sum expenditure that must be made to initiate each attempt to commercialize an idea. This makes financial capital more effective for each attempt, but there is no cumulative effect over time. That is, although the productivity of entrepreneurial effort, e, is increased by the change in $\Delta_{\kappa}$for each attempt, the returns to e do not increase over time as they do for the stocks of applied and basic stocks of knowledge as they increase over time. Thus the only differences one might expect are in magnitudes of effects.

6 The Probability of an Innovative Idea

The availability of entrepreneurial sabbaticals and support in the form of workshops, venture labs, and the like, are only relevant to the extent that a faculty member has an innovative idea. In any period, t, the probability of such an idea is a function of the faculty member's current stocks of knowledge. The parameters in 1, ν_A, ν_B, and ν_E reflect her ability to translate the stocks into an innovative idea.

There are a variety of ways to think of these parameters. Since we have defined an innovative idea as one with commercial potential, it is easy to imagine positive values for ν_E. For research in Pasteur's Quadrant, it is also easy to imagine positive values for ν_B; similarly for ν_A it is not hard to imagine positive values since A_t is patentable knowledge. Indeed, in several of the case studies discussed by Shane (2000), the entrepreneurial opportunity identified came from work in a lab or research modeling.

In terms of managerial policies, it is also common for employees of university venture labs to regularly reach out to faculty to discuss the relation of their research to ideas that might be developed into commercial entities. Finally, as discussed by Shane (2004), positive values of ν_A and ν_B may well reflect the culture of a particular university or the prevalence of entrepreneurial mentors in a faculty member's department.

Figures 6 and 7 show the results of increases in the values for ν_A and ν_B,respectively. Figure 6 assumes the value of ν_A =.5 (a five fold increase over the benchmark) with all other parameter values are as in the benchmark. Figure 7 assume the value of ν_B =.5 with all other parameter values as in the benchmark.

Several results stand out. As in our other experiments, the probability of exit is virtually unchanged from the benchmark until period 20. Moreover, there are many more cases of hybrid entrepreneurship than exit. Notably, however, the increased values of ν_A and ν_B lead to higher entrepreneurial effort than any of the other experiments and the effects on the stock on entrepreneurial knowledge is higher than in other cases.

7 Entrepreneurial Success, Ideas, and Research

In this section, we consider changes in parameters associated with entrepreneurial experience. Figure 8 shows the results from increasing Δ_{EE} from 1 to 5, with all other parameters as in the benchmark. Figure 9 shows the case where the influence of entrepreneurial experience on the probability of an idea ν_E is increased from .1 to .5. Finally, Figure 10 shows the results of allowing entrepreneurial experience to influence the success of applied or basic research ($\Delta_{EA} = 5$).

While none of these experiments shed light on university management practices, they are worth considering as they confirm patterns from the prior experiments. For example, comparison of Figure 8 with Figures 3 and 4 shows that increases in the productivity of entrepreneurial effort which stem from prior entrepreneurial experience are quite similar to those from university management practices. In particular, an increase in Δ_{EE} leads to a decrease in entrepreneurial effort and exit late in the career. Thus the stocks of research knowledge show little effect. Similarly in Figure 9, while the figure shows a decrease in entrepreneurial experience relative to the benchmark, the magnitude is negligible.

Most interesting among the effects of entrepreneurial experience, is the case of benefits from such experience on productivity of applied effort, shown in Figure 10 Not surprisingly these benefits induce more time in entrepreneurial activity, and time spent in applied research decreases since the productivity of applied effort has increased, all else equal. Thus, as in Section 5, when there is a spillover from one type of stock to the productivity of another type of effort, the faculty member will reduce effort in the more productive activity and increase effort in the activity that is a source of the spillover in order to build up that knowledge stock.

However, the reduction in time spent in a particular type of activity does not necessarily translate to a decrease in the associated stock. As Figure 10 demonstrates, the stock of applied research increases relative to the benchmark as a result of the increase in productivity. This in turn has a positive effect on the stock basic research because of Pasteur's Quadrant type spillovers. The stock E also goes up due to an increase in the effort e itself. Finally, this is the only case we consider in which the probability of entrepreneurial exit exceeds that of hybrid entrepreneurship.

8 Conclusion

We have developed and analyzed a life-cycle model of faculty research which allows us to examine the extent to which a faculty researcher engages in entrepreneurial activity when it is possible to take sabbatical leaves to commercialize ideas based on her research. In each period, the researcher allocates her time among applied and basic research, entrepreneurial activity, and leisure. Entrepreneurial effort is relevant only if she identifies an innovative idea that provides an entrepreneurial opportunity. The probability she has such an idea is a function of her research and entrepreneurial knowledge stocks. Conditional on having an innovative idea, she may ignore it, pursue it within the consulting limits of her contract, or take an entrepreneurial sabbatical. Her utility depends on time spent in applied and basic, salary, and expected profit when she is entrepreneurial. Production of applied, basic, and entrepreneurial knowledge is probabilistic.

The most interesting result is that, without substantial supplements to her income, she is very unlikely to take a sabbatical leave. When she does, it is well into her career. In addition, mechanisms designed to make her entrepreneurial effort more productive, such as workshops, venture labs, or technology parks, merely reduce the likelihood that she will take sabbaticals. Instead, these policies increase the likelihood that she will pursue entrepreneurship without taking a leave.

Our analysis makes a variety of simplifying assumptions. Future research could examine the implications of relaxing some of them. For example, we have abstracted from tenure. Prior studies have generally shown that, because activities such as applied research and entrepreneurship do not "count" toward tenure, a faculty researcher defers devoting time to them until after tenure is awarded. It seems evident that including patents and technology commercialization in tenure criteria will alter this result. Faculty who are so inclined will begin applied research and entrepreneurial activities as soon as possible, rather than wait for tenure.

We also assume that each idea has one shot at success; it is either proven a success or failure immediately in the period in which the research first tries to implement it. One can think of stockpiling ideas, so that at each stage the researcher can decide which, if any, of her current stock of ideas she wants to try to implement. This would allow the possibility of entrepreneurship at any stage after the first idea is developed, and so perhaps increase entrepreneurial activity. However, this approach also requires a more sophisticated information structure, so that one try at entrepreneurship with an idea does not reveal the truth about it, but merely provides information that changes the estimated probability it will eventually succeed. Such an extension is well beyond the scope of this paper.

We have also abstracted from the decay or obsolescence of research and entrepreneurial knowledge. Prior studies have generally assumed that knowledge stocks decay, or that some fraction of them becomes obsolete, or both. It is straightforward to determine the effect of relaxing these assumptions on our main result. If decay or obsolescence of knowledge occurs, then taking a leave to be a full-time entrepreneur is more (less) likely if decay increases (decreases) the researcher's salary on leave compared to that as a full-time faculty member. A priori, we see no strong case to be made in favor of knowledge decay increasing or decreasing entrepreneurial salary versus faculty salary, and therefore see no obvious change in results.

Finally, we do not allow cheating in the form of conflict of commitment. The model solution at each stage first freely chooses the efforts and leisure. If this solution has time in entrepreneurship less than the maximum allowed under contract, then we get the hybrid case. However, if this solution gives entrepreneurial effort greater that the maximum, then the researcher has two choices: hybrid with time spent in entrepreneurship at the maximum allowed, or exit to be a full-time entrepreneur. As noted above, we solve both of these problems and assume the researcher selects the one with the larger expected present discounted value of utility. However, it is also possible that the unconstrained maximum involves entrepreneurial effort strictly greater than the maximum allowed, but less than effort if exit occurred. In these cases, there is an obvious incentive for the researcher to shirk on university research in favor of entrepreneurship (especially of the exit salary is low). Concerns about this type of conflict of commitment have been expressed about all forms of consulting for a very long time. This problem is an interesting one as well, but modeling it would require introducing some stochastic enforcement mechanism, so it also is well beyond the scope of this paper.

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9 Backward induction

We use backward induction to solve for the optimal choices for each combination of research knowledge stocks A, B and entrepreneurial stock E, starting with the last period T.

1. We solve for the optimal efforts a_T^*, b_T^* in applied and basic research for the value function $V_{t,NoInnov}$ in the event the faculty does not have any innovation.

2. In the presence of an innovation, we first solve for the optimal efforts a_T^*, b_T^* in applied and basic research, and e_T^* in entrepreneurial effort assuming only that the effort levels are non-negative and sum up 1 at most. The fractions of time in applied and basic research are guaranteed to be positive due to the nature of the Cobb-Douglas function. The first order conditions are

$$\begin{aligned}\frac{\partial V_t}{\partial a_t} &= \gamma_a a_t^{\gamma_a - 1} b_t^{\gamma_b} - (1-\gamma_a-\gamma_b-\gamma_e)(1-a_t-b_t-e_t)^{-\gamma_a-\gamma_b-\gamma_e} \\ &+ \beta \frac{\delta_a + \Delta_{AA}A_t + \Delta_{BA}B_t + \Delta_{EA}E_t}{(1+(\delta_a + \Delta_{AA}A_t + \Delta_{BA}B_t + \Delta_{EA}E_t)a_t)^2} \times \\ &\sum^{B_{t+1}} \sum^{E_{t+1}} P(B_{t+1}, E_{t+1})(V(A_t+1, B_{t+1}, E_{t+1}) - V(A_t, B_{t+1}, E_{t+1})) \\ &= 0, \end{aligned} \tag{11}$$

$$\begin{aligned}\frac{\partial V_t}{\partial b_t} &= \gamma_b a_t^{\gamma_a} b_t^{\gamma_b - 1} - (1-\gamma_a-\gamma_b-\gamma_e)(1-a_t-b_t-e_t)^{-\gamma_a-\gamma_b-\gamma_e} \\ &+ \beta \frac{\delta_b + \Delta_{AB}A_t + \Delta_{BB}B_t + \Delta_{EB}E_t}{(1+(\delta_b + \Delta_{AB}A_t + \Delta_{BB}B_t + \Delta_{EB}E_t)b_t)^2} \times \\ &\sum_{A_{t+1}} \sum_{E_{t+1}} P(A_{t+1}, E_{t+1})(V(A_{t+1}, B_t+1, E_{t+1}) - V(A_{t+1}, B_t, E_{t+1})) \\ &= 0, \end{aligned} \tag{12}$$

$$\begin{aligned}\frac{\partial V_t}{\partial e_t} &= \gamma_e e_t^{\gamma_e - 1} - (1-\gamma_a-\gamma_b-\gamma_e)(1-a_t-b_t-e_t)^{-\gamma_a-\gamma_b-\gamma_e} \\ &+ \alpha \frac{\Delta_{AE}A_t + \Delta_{BE}B_t + \Delta_{EE}E_t + \Delta_\kappa \kappa}{(1+(\Delta_{AE}A_t + \Delta_{BE}B_t + \Delta_{EE}E_t + \Delta_\kappa \kappa)e_t)^2} A_t^{\phi_A} B_t^{\phi_B} E_t^{\phi_E} \\ &+ \beta \frac{\Delta_{AE}A_t + \Delta_{BE}B_t + \Delta_{EE}E_t + \Delta_\kappa \kappa}{(1+(\Delta_{AE}A_t + \Delta_{BE}B_t + \Delta_{EE}E_t + \Delta_\kappa \kappa)e_t)^2} \times \\ &\sum^{A_{t+1}} \sum^{B_{t+1}} P(A_{t+1}, B_{t+1})(V(A_{t+1}, B_{t+1}, E_t+1) - V(A_{t+1}, B_{t+1}, E_t)) \\ &= 0, \end{aligned} \tag{13}$$

where the expressions associated with the expected discounted value functions are omitted for $t = T$.

(a) If the entrepreneurial effort $e_T^* = 0$, the faculty's value function is V_{T_P} and equals $V_{T,NoInnov}$ since she does not engage in any entrepreneurial activity.

(b) If the entrepreneurial effort e_T^* is greater than $> \overline{e}$, the faculty exits academia to become an entrepreneur if $V_{T_E} > V_{T_{PE}}$ where V_{T_E} is the value function reoptimized with respect to e_T and $a_T = b_T = 0$, $V_{T_{PE}}$ is the value function reoptimized with respect to a_T, b_T and $e_T = \overline{e}$. Otherwise, she makes the hybrid choice with the maximum amount of time $\overline{e}$ in entrepreneurship allowed by the university.

(c) If the entrepreneurial effort e_T^* is less than or equal to $\overline{e}$ and positive, the faculty's value function is $V_{T_{PE}}$ and she makes the hybrid choice. We then obtain $V_{T,Innov}$.

3. Backing one period to $t = T - 1$, the faculty maximizes her value functions for when she has an innovation ($V_{T-1,Innov}$) and when she does not ($V_{T-1,NoInnov}$) given that the expected value function $\mathbf{E}(V_T) = (1 - P_I)V_{T,NoInnov} + P_I V_{T,Innov}$.

4. Repeat steps 1-3 until $t = 1$.

5. We finally obtain a set of optimal efforts ($a^*_{t,NoInnov}(A, B, E)$, $b^*_{t,NoInnov}(A, B, E)$, and $e^*_{t,NoInnov}(A, B, E)$) for when she has no innovation and ($a^*_{t,Innov}(A, B, E)$, $b^*_{t,Innov}(A, B, E)$, and $e^*_{t,Innov}(A, B, E)$) for when she has an innovation in all time periods t=1,..,T and for all combinations of knowledge stocks.

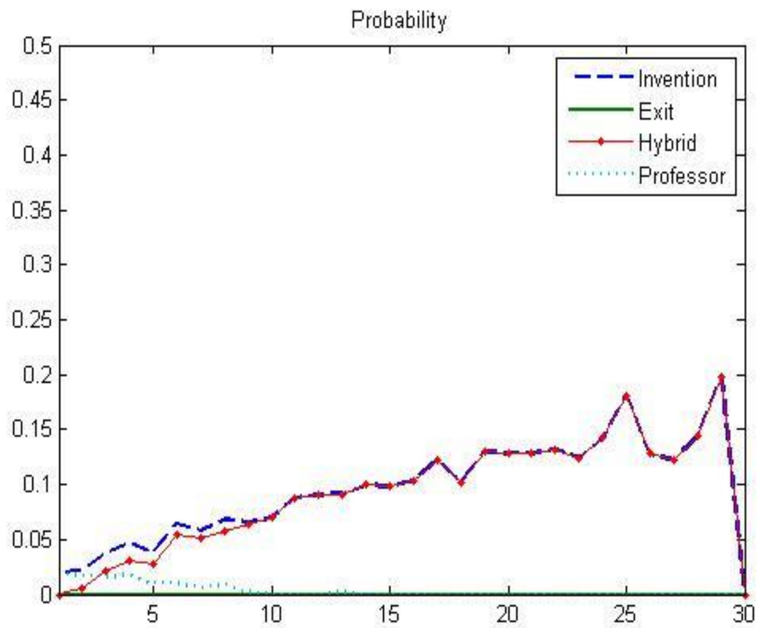

Figure 1a

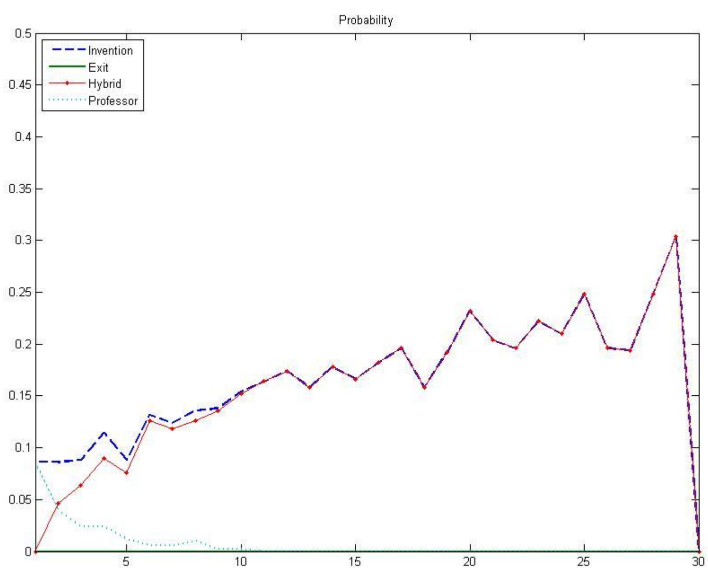

Figure 1b

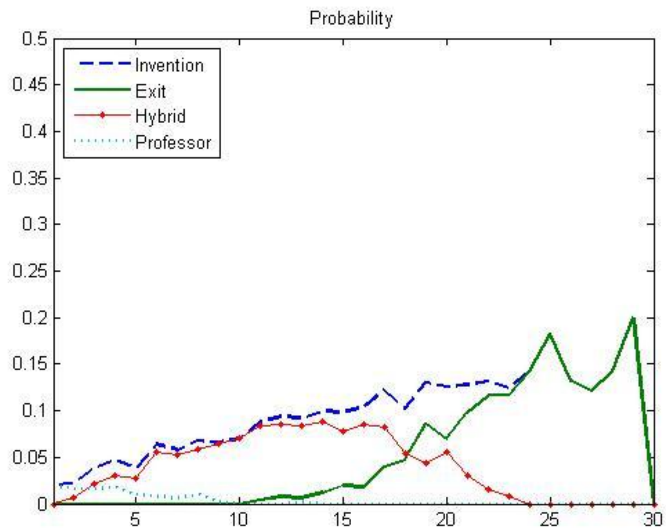
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Figure 1c

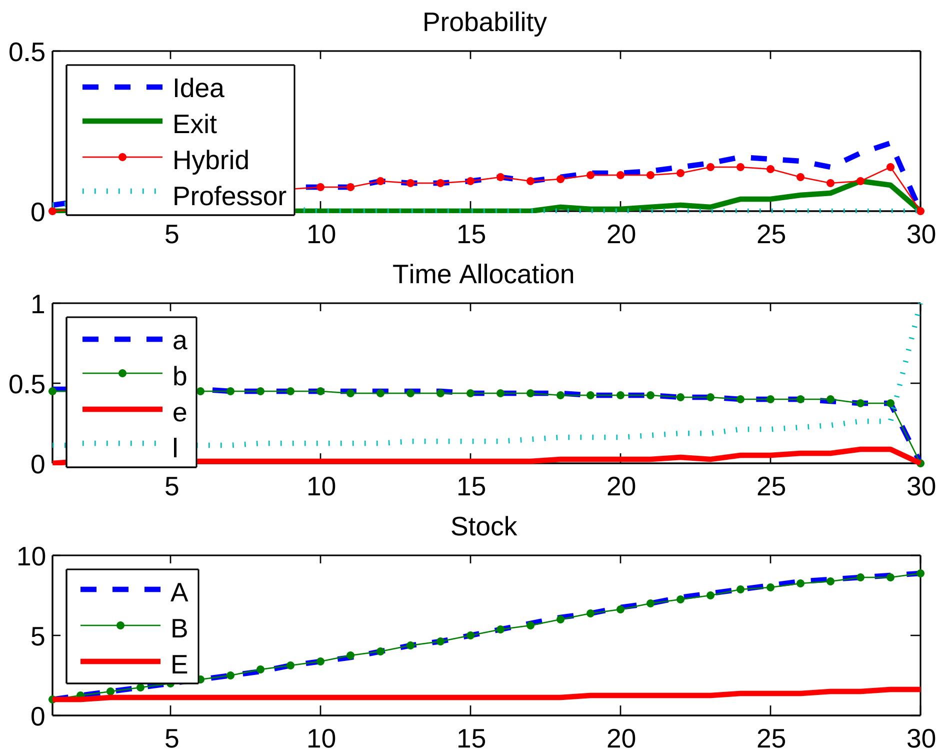
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Figure 2

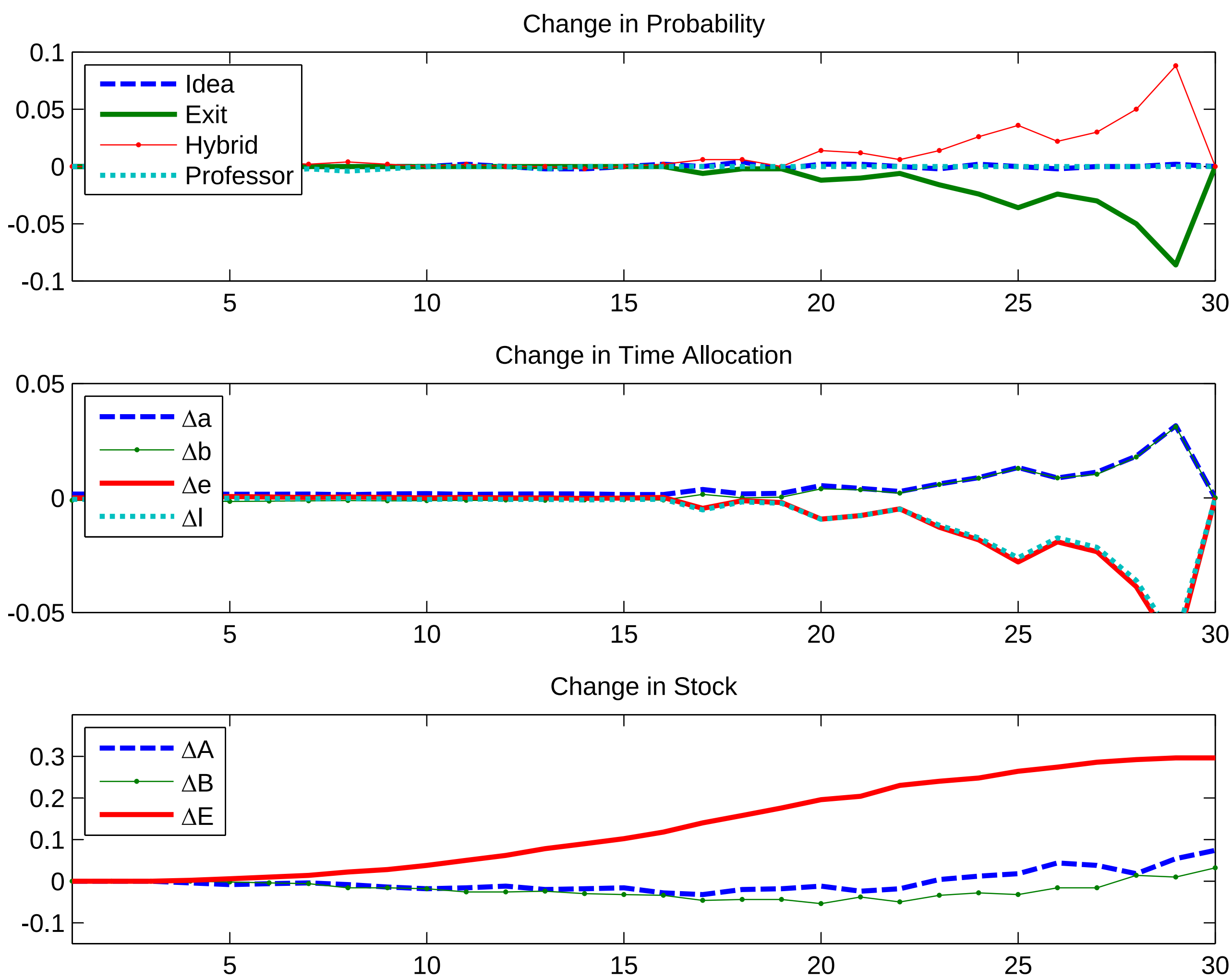

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Figure 3

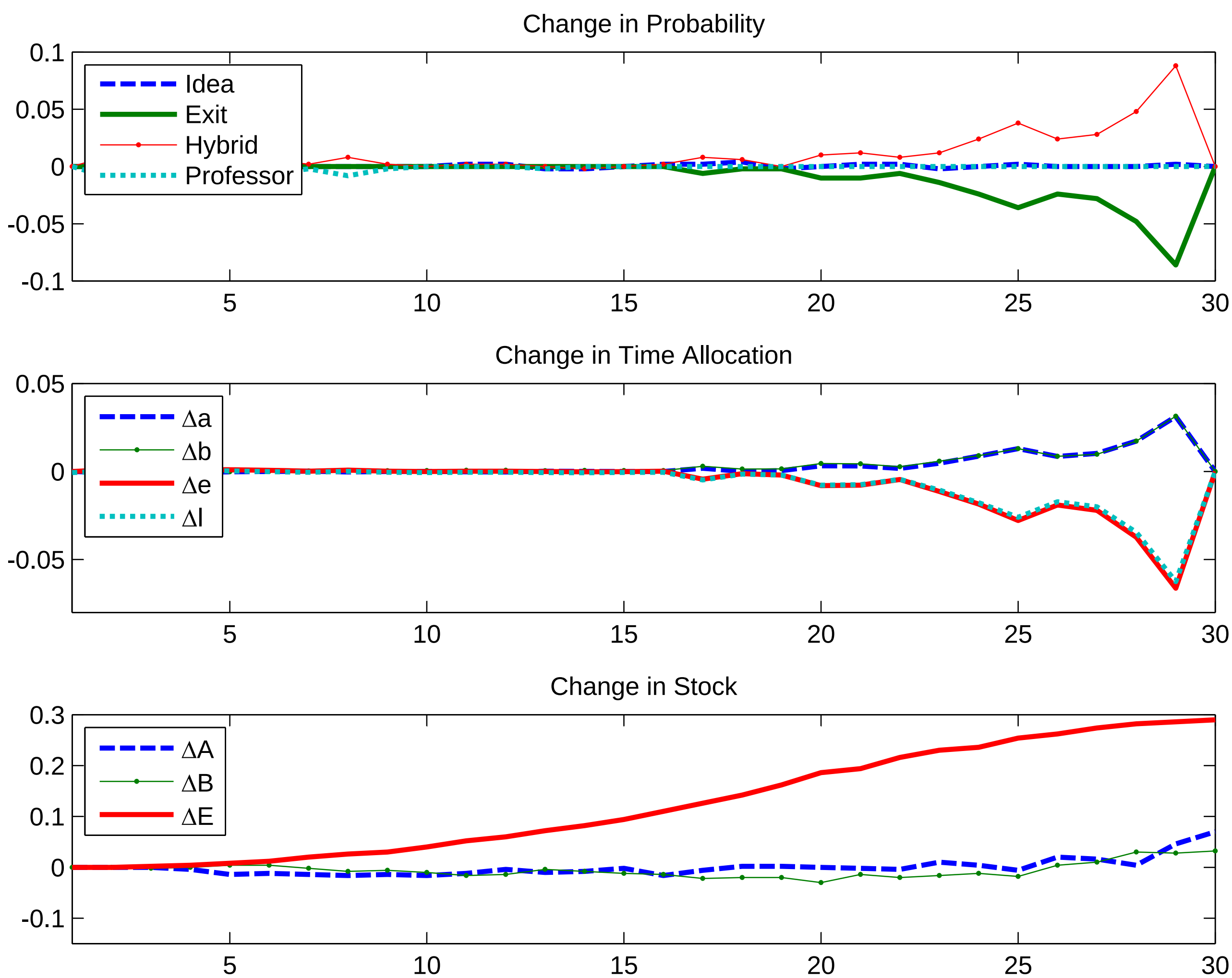

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Figure 4

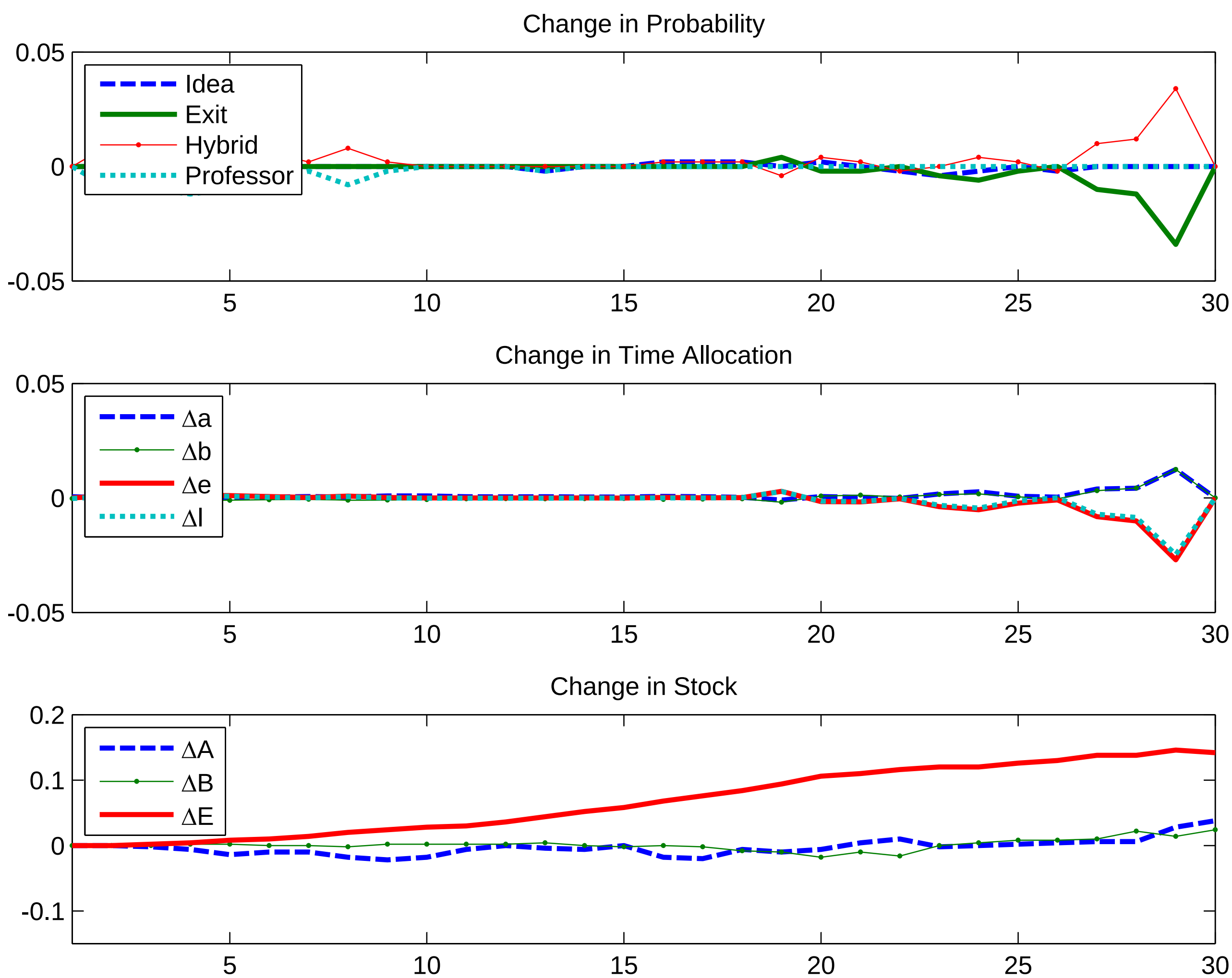
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Figure 5

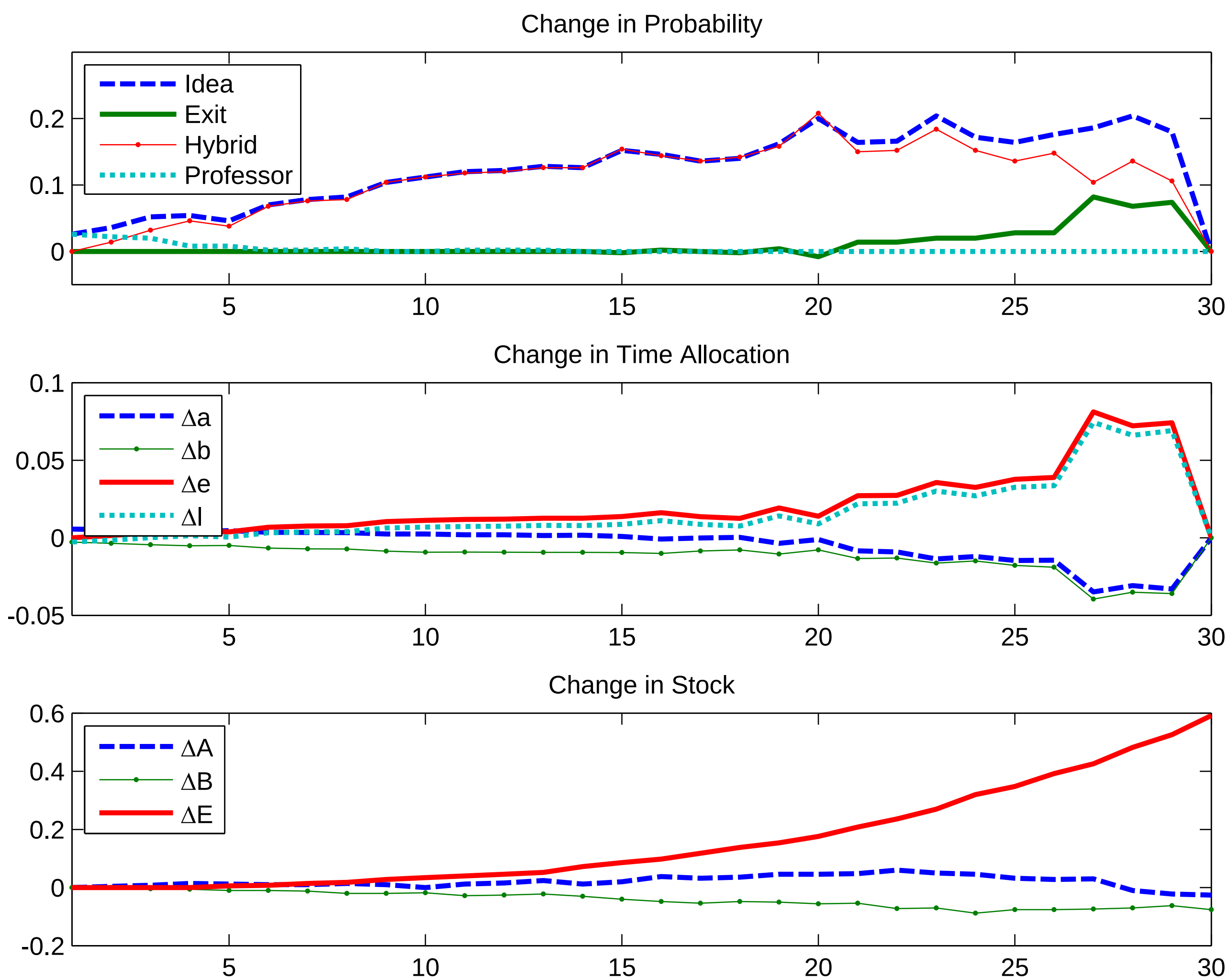
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Figure 6

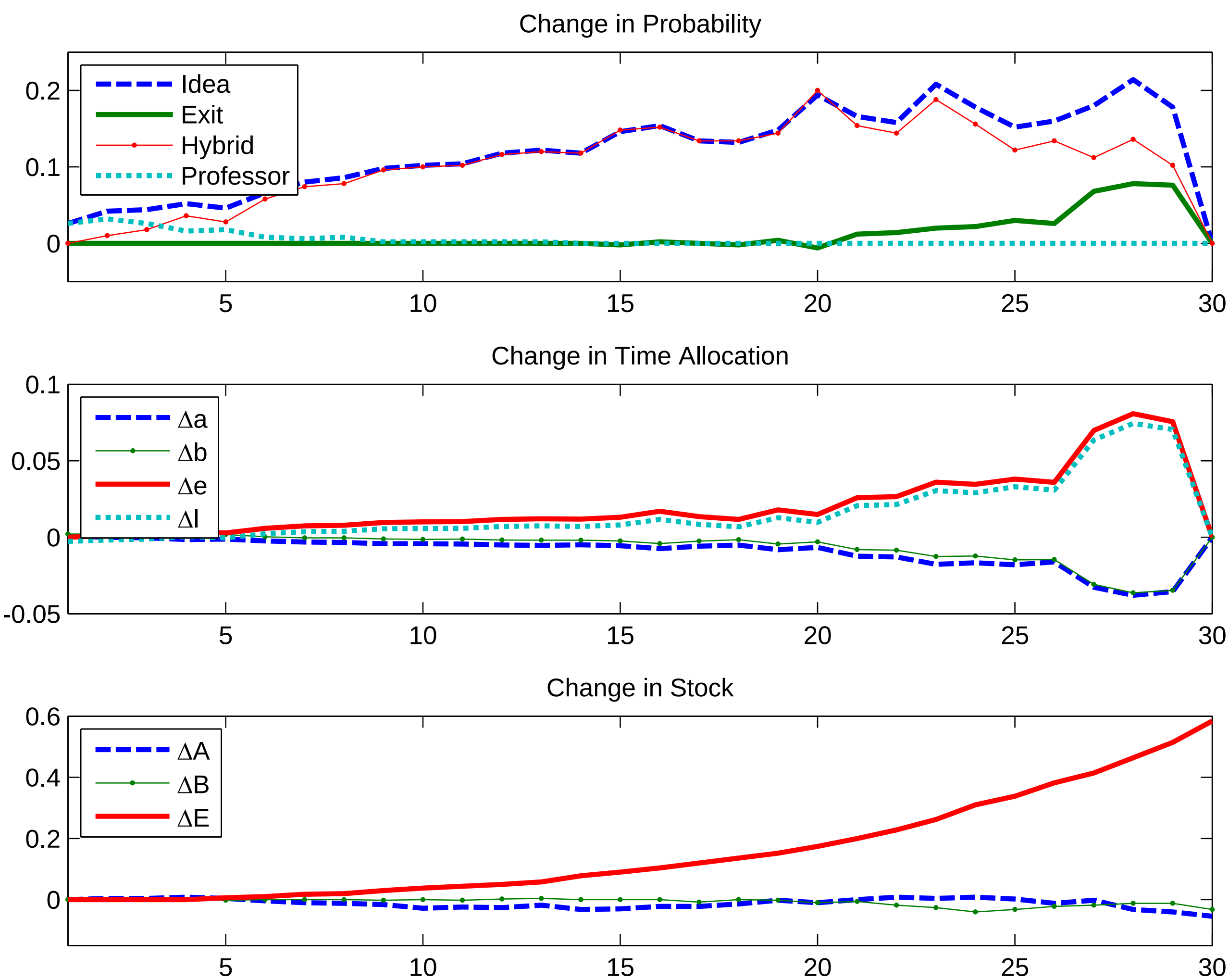
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Figure 7

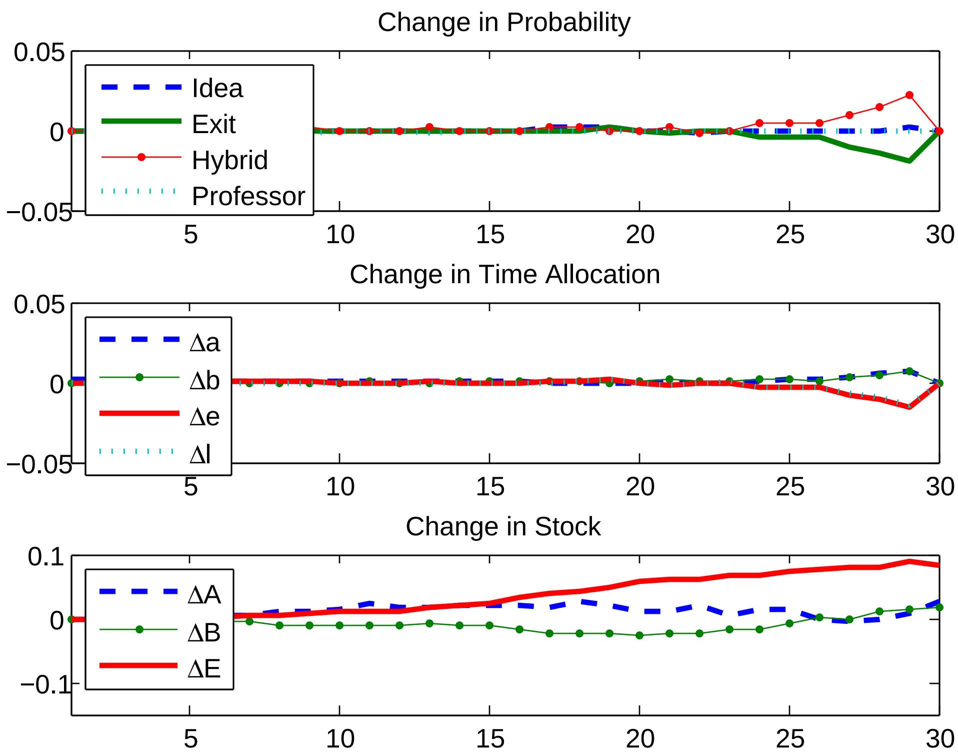
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Figure 8

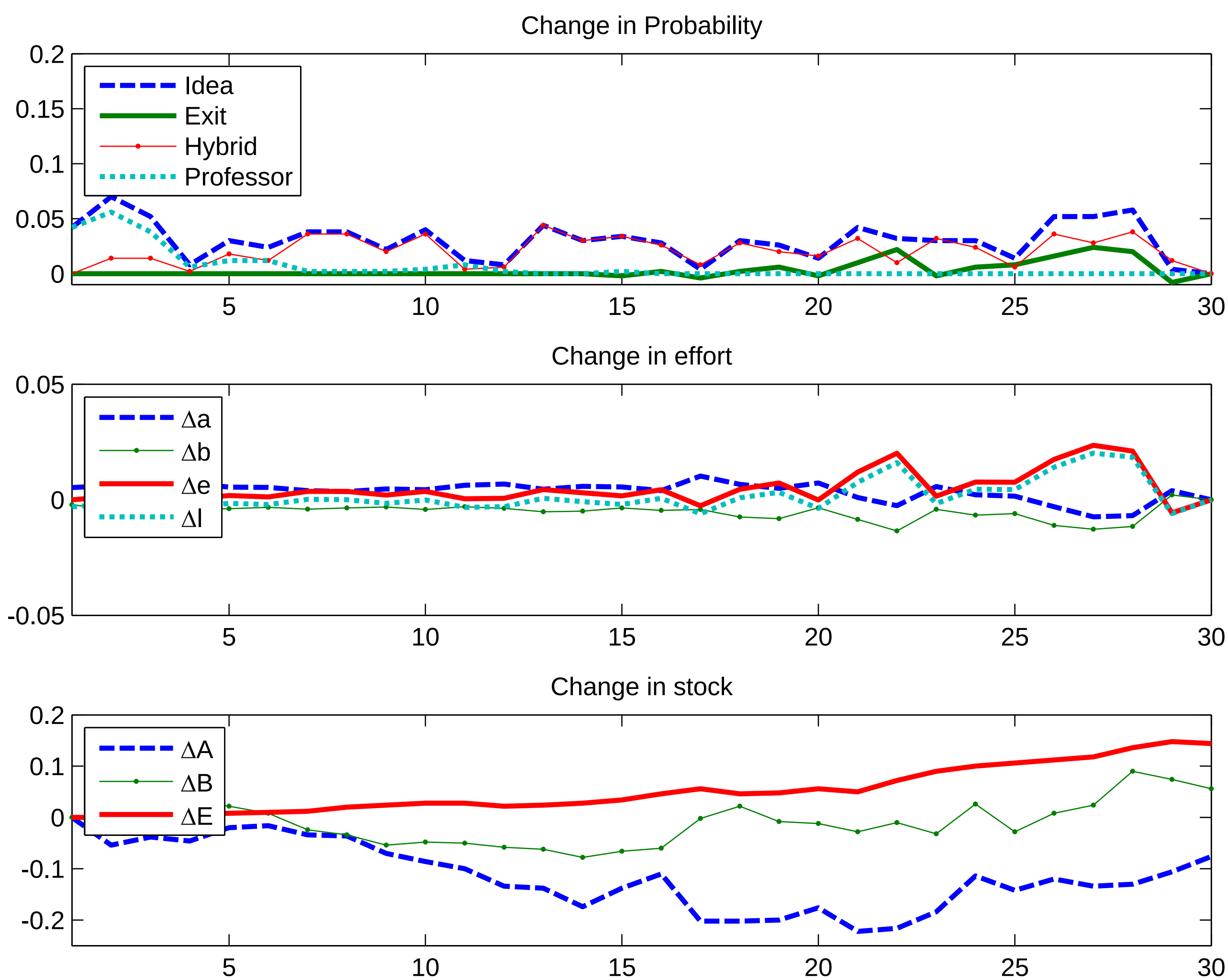
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Figure 9

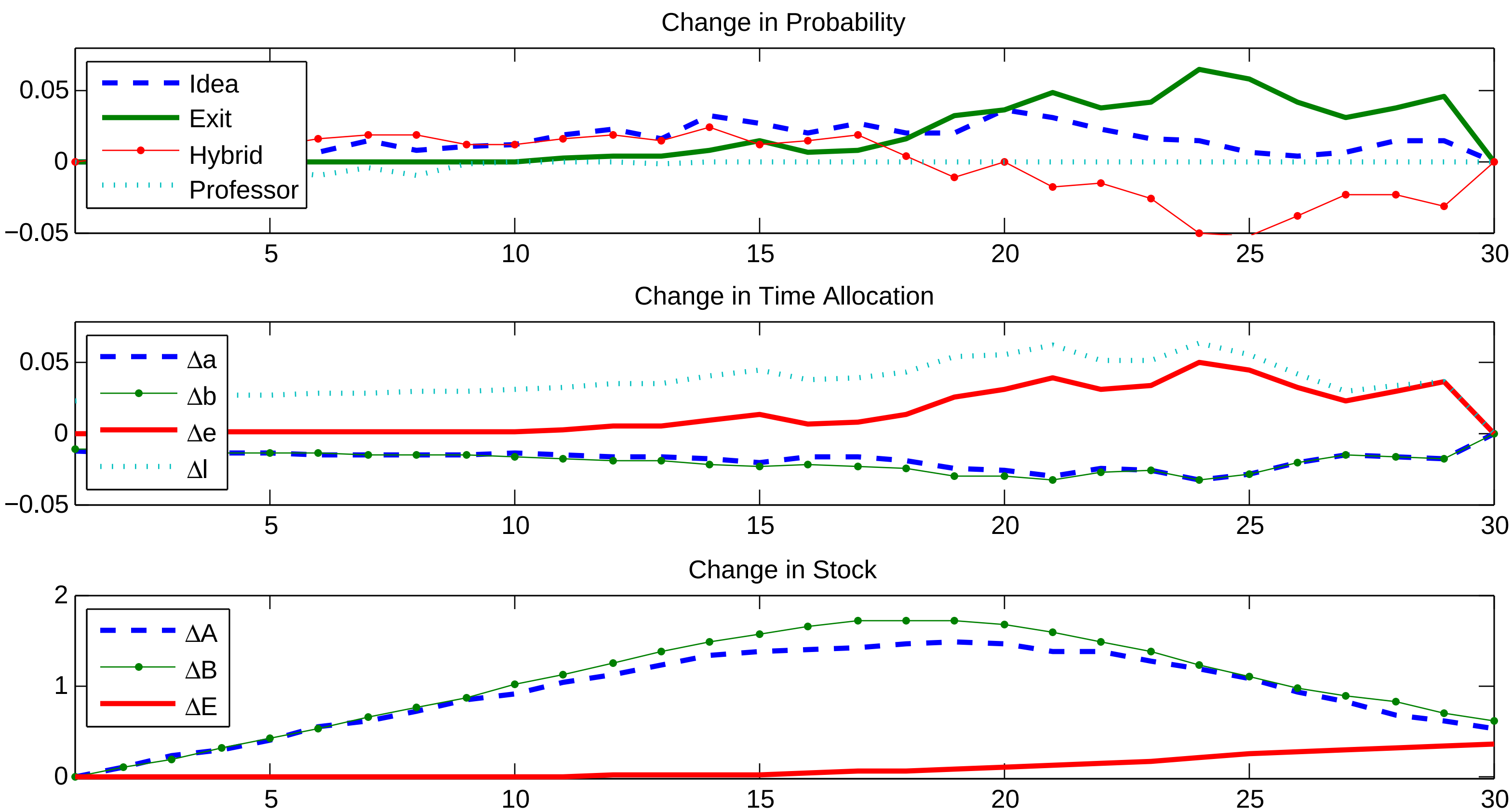

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Figure 10