REAL OPTIONS: ADDED RETURN VERSUS ADDED RISK

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Abstract

A key benefit of real options is that they provide a firm with an additional return, above the expected discounted net cash flow that the firm would receive from the indiscriminate use of its resources. Some research on strategic resource allocation informally speculated that, along with providing a firm with an extra return, real options can help that firm reduce its risk. The empirical corroboration of availability of such dual benefits for firms has been limited because that idea was never carefully developed theoretically. This study develops a formal model that demonstrates how four popular real options affect a firm's risk. With a few qualifications, a firm's risk is shown to be increased by real options. In addition to explaining this baseline result and the exceptions leading to the risk-reduction, this study develops a systematic account of how risk associated with real options derives from determinants of real options.

Keywords: real options, risk, return, resource allocation.

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Real Options: Added Return *versus* Added Risk

A key benefit of real options is that they increase the value of a firm that holds them or, in other words, lead to an additional return—above the expected discounted net cash flow that derives from the indiscriminate use of that firm's resources. The discretional (*i.e.*, optional) and discriminate (*i.e.*, only in response to specific contingencies) exercising of real options gives a firm an additional return because that firm can flexibly allocate its resources to a better use with favorable resolution of uncertainty, thereby exploiting the upside potential when, what is usually said, such real options are "in the money." When, by contrast, resolution of uncertainty is unfavorable, real options are "out of the money," and the firm keeps its resources in their original use, thus preserving in such unfavorable scenarios the same return as without real options. In addition to that intuitive property of real options such that their discretional and discriminate use provides a firm with an extra return, an ensuing property common to all real options is that the added return increases in uncertainty because uncertainty spurs future favorable scenarios in which real options get in the money. Furthermore, the net return added by real options naturally declines in the cost of exercising them.

With the involved discretional and contingent allocation of resources, real options represent subtle and intriguing resource allocation strategies that have been at the focus of research in finance, operations, strategic management, and other academic areas. Among real options studied in academic research are (a) "the time-to-build option," with which a firm can grow its business incrementally by acquiring additional resources; (b) "the option to abandon," with which a firm can divest its resources by selling them on a secondary market; (c) "the option to alter operating scale," with which a firm can idle, or shut down, the use of its resources temporarily with the possibility to reengage these resources in the future; and (d) "the option to

switch outputs," with which a firm can withdraw its resources from one product or geographic market and redeploy, or switch, them to another market (Trigeorgis, 1993: Exhibit 1).

Although empirical contexts in which the four noted real options are present to firms vary very broadly, the ways in which an additional return is created can be exemplified with an oil-drilling firm that operates a rig to drill a well in an oil field that has its field-specific demand for oil-drilling services and an associated return to operating a rig in that field. That firm holds the time-to-build option (*i.e.*, item "a" above) with which an early investment into the use of the drilling rig in the oil field lets the firm better learn the evolution of demand for oil-drilling services in that field and, if such demand turns out to be high, expand operations by buying another rig and deploying it in the field, instead of attaining only part of such an improvement in demand with only one original rig. Alternatively, if demand for oil-drilling services happens to be low, the firm can exercise the option to abandon (*i.e.*, item "b" above) by selling its rig in a secondary market for technological resources and cashing out of the business in the original field, instead of generating a low or even negative return in that field. A less radical response to low demand would be to use the option to alter operating scale (*i.e.*, item "c" above) by stacking the rig and, possibly, reopening it when the demand turns high again, instead of continuing to generate a low or even negative return during the downturn in demand. Still another reaction to the low demand for drilling services in the home oil field is to use the option to switch outputs (*i.e.*, item "d" above) by redeploying the rig to another oil field (*i.e.*, the destination for the switching of the rig) with a higher demand and thus a higher return to the use of the rig, instead of collecting a lower return in the home oil field (*i.e.*, the origin for the use of the rig).

By contrast with the consensus on how real options and their determinants, such as uncertainty and the option exercising costs, affect a firm's return, less clarity exists on how they

affect that firm's risk. Assessment of such risk is commonly conducted by estimating the second moment, or the variance, of the net cash-flow that is forecasted for the indiscriminate allocation of a firm's resources to its business. That approach omits the ramification that a firm can use various real options that will alter allocation of its resources and can change the variance of the net cash-flow of that firm. Some research on strategic resource allocation has tried to account for that subtle ramification qualitatively, by embracing what Tong and Reuer (2007b) named the "metaphoric usage of real options" and what McGrath (1999) and McGrath, Ferrier, and Mendelow (2004) named "real options reasoning," and speculated that, along with increasing a firm's return, real options may help that firm reduce risk (Belderbos, Tong, and Wu, 2014; Chatterjee and Lubatkin, 1990; Folta and Sakhartov, 2015; Miller and Reuer, 1998; Pantzalis, Simkins, and Laux 2001; Reuer and Leiblein, 2000; Tong and Reuer, 2007a). However, the empirical corroboration of that informally posited idea has been limited, apparently because the idea needed to be first better developed theoretically, preferably more rigorously. In other words, a thorough theoretical analysis of how real options affect a firm's risk was missing but was necessary to better know the predictions to be tested empirically, in the first place.

One reason why the referred "metaphoric usage of real options" or "real options reasoning" cannot reliably predict how real options affect a firm's risk is that the assessment of risk in the presence of the noted real options is analytically sophisticated. The discretional and contingent use of real options includes the choice of the optimal time, if any, and of the optimal conditions for their exercising. Furthermore, such use is path-dependent in the sense that, even at the same time and with the same condition, a real option may, or may not, be exercised depending on how the uncertain environment in which a real option is situated evolved into that condition. Meanwhile, the formal analysis of implications of such complex real options for a

firm's risk has recently started for the option to switch outputs (Sakhartov, 2022; 2023) and can be extended to other options to more accurately reflect their impact on a firm's risk.

An additional important motivation for considering how real options affect a firm's risk is that risk is an important measure of a firm's performance that has prominently featured as such in strategic management research since at least Andrews (1971). Accordingly, risk determines the attractiveness for a firm to have and use real options, just as a return to such possession and to such use does. Meanwhile, many formal models of real options (*e.g.*, Kogut and Kulatilaka, 1994; Sakhartov and Folta, 2014; 2015; Triantis and Hodder, 1990) followed the risk-neutral approach of Black and Scholes (1973) and Merton (1973), thus focusing on the expected returns to real options and remaining agnostic regarding how real options affect a firm's risk.

This study develops four semi-analytical models: each model evaluates risk in the modeled firm as the second moment, or the variance, of the accumulated net cash flow, and the firm's return as the first moment, the expectation, of the accumulated net cash flow, when that firm can use one of the four noted American-type real options (*i.e.*, each option can be exercised at any time before the firm's resources fully depreciate). In specifying each option, this study follows precedents for the formalization of that option: (a) for the time-to-build option—Sakhartov and Reuer (2024); (b) for the option to abandon—Feldman and Sakhartov (2021); (c) for the option to alter operating scale—Li, Reuer and Sakhartov (2024); and (d) for the option to switch outputs—Sakhartov and Folta (2014; 2015) and Sakhartov (2022; 2023). The assessment of the firm's return follows the standard backward induction that is subordinated to the general principle of dynamic optimality and formalized with the Bellman equation (Bellman, 1957), like in Sakhartov and Folta (2014; 2015). A by-product of the backward induction is the firm's conditional option-exercising choices (*i.e.*, each choice is conditioned on the unknown, or

assumed, immediate previous choice). The assessment of the firm's risk uses such conditional option-exercising choices as an input and simulates sequences of the firm's unconditional choices for numerous random paths for the evolution of the uncertain environment of the firm. Then, risk is estimated as the variance of the firm's net cash flow accumulated on these simulated paths, like in Sakhartov (2022; 2023). In addition, the firm's return and risk realized with each of the four real options are compared to, respectively, return and risk that the firm realizes in the baseline scenario in which it does not have any real options. These comparisons test whether the considered four real options can indeed reduce the firm's risk as was speculated in previous research. Besides testing whether the considered four real options can reduce the firm's risk, risk associated with each option is related to the essential determinants of such options mentioned above—to uncertainty and to the option exercising cost.

Results for the four real options are illustrated in the respective Figures 1−4. In each figure, two red lines demonstrate the relationships between the firm's return and the option determinant placed along the horizontal axis; two blue lines reveal the relationships between the firm's risk and that option's determinant. In turn, in each figure, two solid lines show the relationships between a firm's performance (*i.e.*, return or risk) and the option's determinant placed along the horizontal axis when the real option considered in the figure is present to the firm; two broken lines indicate the relationships between a firm's performance and that option determinant when the considered real option is absent.

Insert Figure 1 about here

Figure 1 illustrates how the firm's return and risk are determined by the presence of the time-to-build option. In both panels of that figure, the solid red lines are above the respective broken red lines, thus validating the intuitive property that the considered real option provides

the firm with an additional return. In turn, the solid blue lines in both panels of Figure 1 are above the respective broken blue lines, thus demonstrating that the presence of the time-to-build option also increases the firm's risk. In Panel A, uncertainty monotonically raises both the return (*i.e.*, the previously known effect) and the risk (*i.e.*, the newly derived effect) of the firm holding the time-to-build option. In turn, in Panel B of Figure 1, the option exercising cost monotonically decreases both the return (*i.e.*, the previously known effect) and the risk (*i.e.*, the newly derived effect) of the firm holding the time-to-build option, in both cases to the levels faced by the firm when it does not have that real option.

Figure 2 reveals how the firm's return and risk are affected by the option to abandon. Like in Figure 1, in both panels of Figure 2, the solid red lines are above the respective broken red lines, thus corroborating the definitional property that the real option raises the firm's return. However, in contrast to Figure 1, the solid blue lines in both panels of Figure 2 are below the respective broken blue lines, thus demonstrating that the presence of the option to abandon reduces the firm's risk. In Panel A of Figure 2, uncertainty still monotonically enhances both the return (*i.e.*, the previously known effect) and the risk (*i.e.*, the newly derived effect) of the firm holding the real option. In Panel B of Figure 2, the option exercising cost monotonically reduces the firm's return (*i.e.*, the previously known effect) but monotonically increases the firm's risk (*i.e.*, the newly derived effect), in both cases to the levels faced by the firm when it does not have the real option.

Insert Figure 2 about here

Figure 3 shows how the firm's return and risk are shaped by the option to alter operating scale. Like the previous two figures, the real option gives the firm an additional return. Unlike in Figure 1 for the time-to-build option but like in Figure 2 for the option to abandon, the option

to alter operating scale cuts the firm's risk. In Panel A of Figure 3, uncertainty still monotonically positively affects both the return (*i.e.*, the previously known effect) and the risk (*i.e.*, the newly derived effect) of the firm holding the option to alter operating scale. In Panel B of Figure 3, the option exercising cost monotonically reduces the return (*i.e.*, the previously known effect) but monotonically increases the risk (*i.e.*, the newly derived effect) to the levels in the firm without the real option.

Insert Figure 3 about here

Figure 4 demonstrates how the firm's return and risk are influenced by the option to switch outputs. There are more panels in Figure 4 than in each of the preceding figures because, with the option to switch outputs, uncertainty becomes multivariate, and the illustration of the results needs to assess two additional ramifications of such uncertainty—uncertainty in the destination for the switching of the firm's resources and correlation of sources of uncertainty between the origin and the destination. In all panels of Figure 4, the solid red lines are above the respective broken red lines, thus reflecting the intuitive property that the real option provides the firm with an extra return. Furthermore, except for the case of low uncertainty in the destination for the switching in the left part of Panel B, the solid blue lines stand above or at least at the same level as the respective broken blue lines in al panels of Figure 4, meaning that the option to switch outputs mostly entails an additional risk. Uncertainty in the origin (*i.e.*, Panel A of Figure 4) or in the destination (*i.e.*, Panel B of Figure 4) continues to monotonically enhance both the return (*i.e.*, the previously known effect) and the risk (*i.e.*, the newly derived effect) of the firm holding the real option. In turn, the option exercising cost in Panel D of Figure 4 monotonically reduces both the return (*i.e.*, the previously known effect) and the risk (*i.e.*, the newly derived effect) in the firm holding the option to switch outputs to the levels without the

real option. Panel C of Figure 4 demonstrates the previously known result (*e.g*., Sakhartov and Folta, 2015; Triantis and Hodder, 1990) that the return added by the option to switch outputs monotonically declines in correlation of sources of uncertainty between the origin and the destination for the switching of the firm's resources. Finally, Panel C of Figure 4 shows a new result such that the risk added by the option to switch outputs has an inverted U-shaped relationship with correlation of sources of uncertainty between the origin and the destination for the switching of the firm's resources.

Insert Figure 4 about here

The results reported above can now be used to address the motivating query of how real options affect a firm's risk. Do real options indeed reduce a firm's risk, just as they raise that firm's value and just as it was speculated in some research on strategic resource allocation that relied on the "metaphoric usage of real options" also known as "real options reasoning"? The correct answer is not "yes." Instead, the correct answer to that important question depends on what happens with the randomness of the firm's cash flow after various real options are exercised. The correct answer can be summarized as the baseline prediction that is just opposite to the previously held belief when the following three qualifications are added. Unless the randomness of the firm's cash flow (i) is completely terminated by the exercising of a real option, as is the case with the option to abandon when the sold resources fully stop generating cash flow for the firm; (ii) is contained temporarily by the exercising of a real option, as is the case with the option to alter operating scale when the idled resources stop generating cash flow for the firm at least for some time; or (iii) goes down with the option to switch outputs in the special case when the destination provides less uncertain cash flow than the original use for the firm's resources, the presence of real options *increases* a firm's risk. Only the special conditions

mentioned in the three qualifications above may lead to the previously expected dual benefits for the firm such that a real option, at once, improves a firm's performance in both dimensions—increases the firm's return and *reduces* the firm's risk.

With the baseline prediction summarized above, the added risk increases monotonically in uncertainty and decreases monotonically in the option exercising cost, just as the firm's additional return is similarly affected by these option determinants. In all the three exceptional cases, the added risk continues to increase monotonically in uncertainty, just as the firm's additional return is similarly affected by that option determinant. In one of those exceptional cases (*i.e.*, "iii"), the effect of the option exercising cost on the firm's risk is still negative, similar to how that cost negatively affects the firm's additional return. Meanwhile, in two out of the three exceptional cases (*i.e.*, "i" and "ii"), the effect of the option exercising cost on the firm's risk counterintuitively reverses from negative to positive. This reversal happens because very high option exercising costs become prohibitive for the use of a real option and the firm avoids the use of the prohibitively expensive option that could otherwise reduce the firm risk below the level without that option. As a result of that reversal, some real options (*i.e.*, the option to abandon and the option to alter operating scale) lead to the oppositely directed effects of their key determinant, the option exercising cost, on the firm's return and on the firm's risk. To reiterate, in these interesting cases, the firm's return monotonically declines in the option exercising cost, whereas the firm's risk monotonically increases in the option exercising cost. Finally, the most complex of the considered four real options, the bivariate option to switch outputs entails a partial convergence (*i.e.*, with positive correlation) and partial divergence (with negative correlation) of the effects of its key determinant, correlation of sources of uncertainty between the origin and the destination on the firm's added return and added risk.

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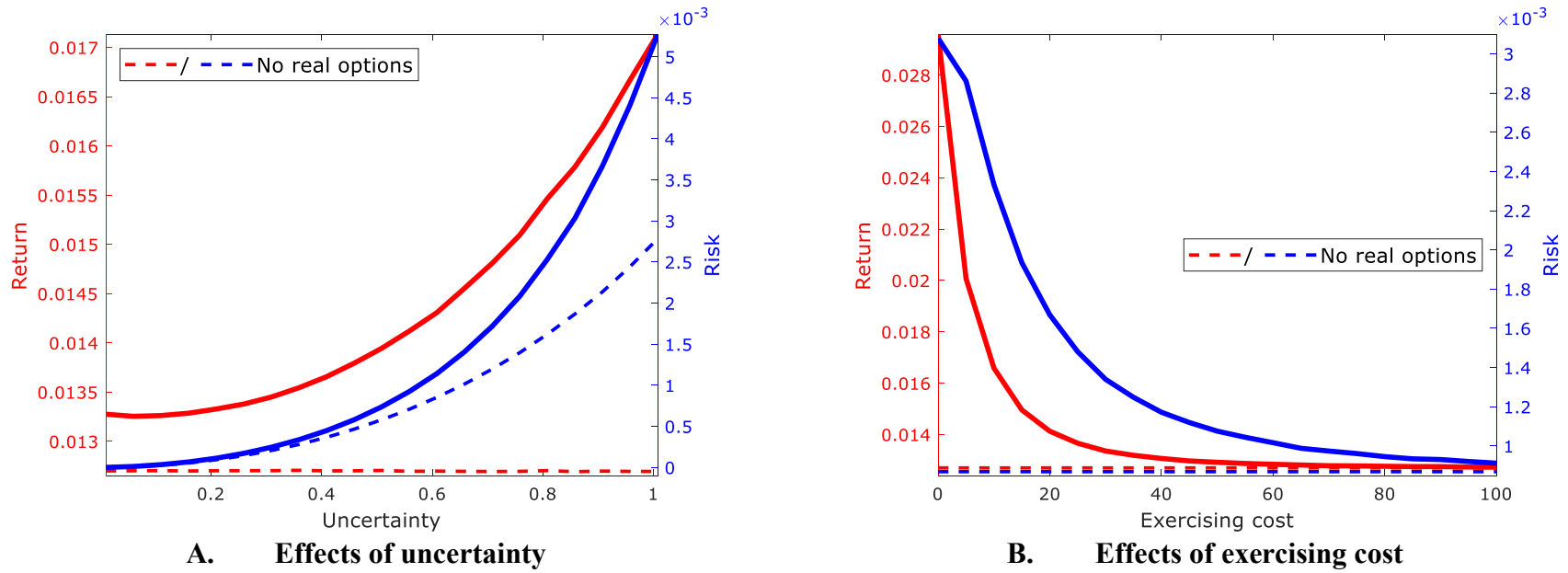**Real Options: Added Return *versus* Added Risk**

A.   **Effects of uncertainty**

B.   **Effects of exercising cost**

Figure 1. Time-to-build option

Real Options: Added Return *versus* Added Risk

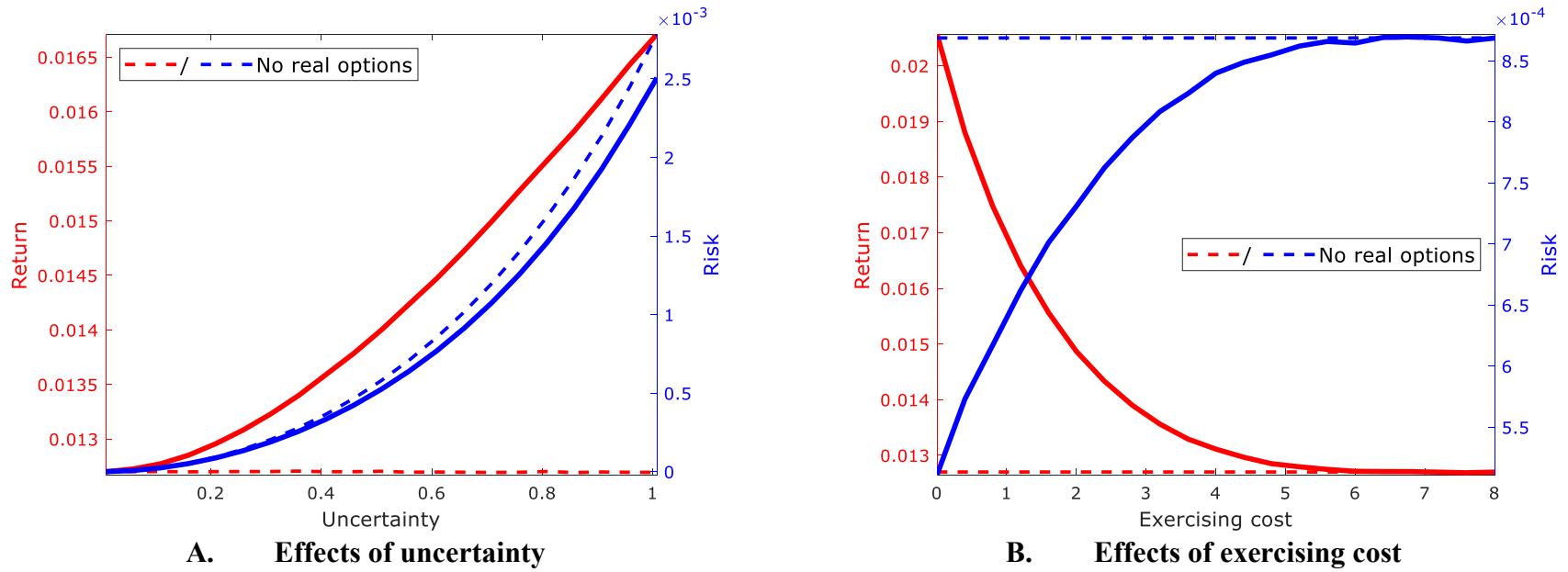A. **Effects of uncertainty**   B. **Effects of exercising cost**
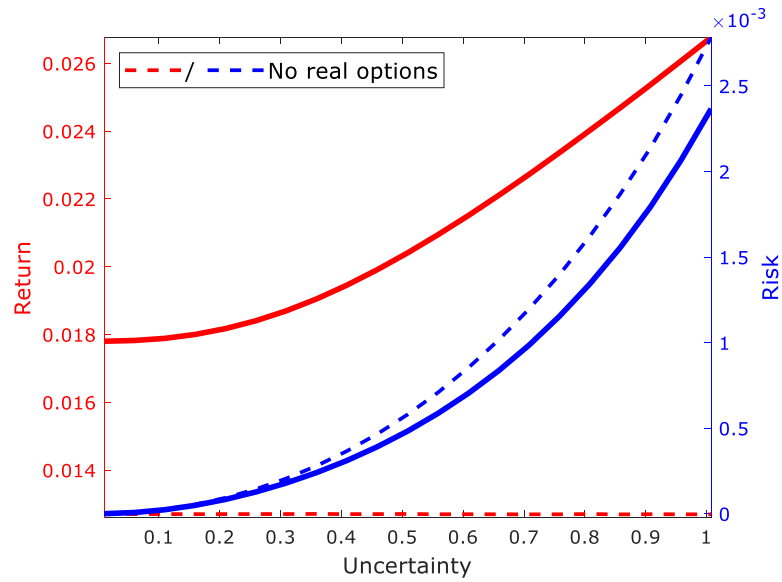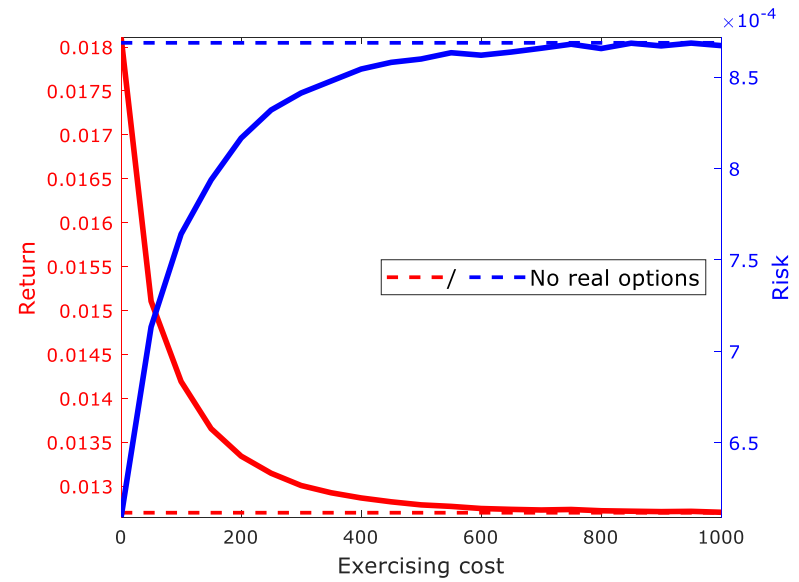
Figure 2. Option to abandon
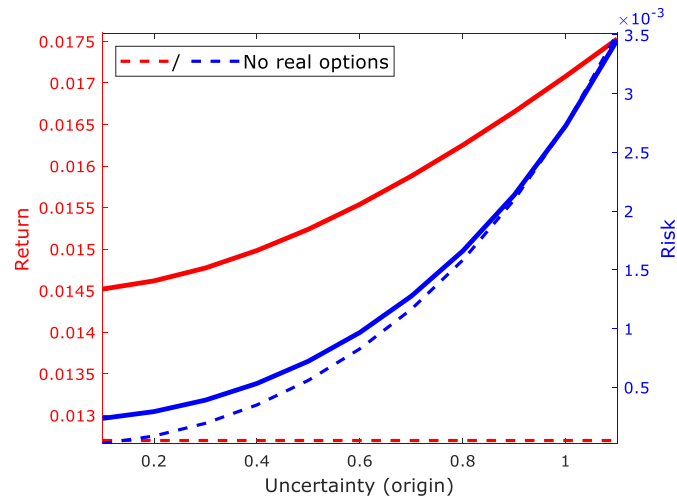
Real Options: Added Return *versus* Added Risk

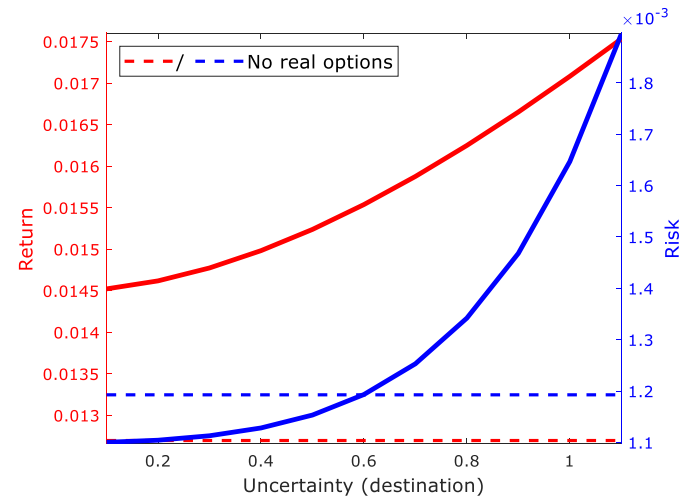A.   **Effects of uncertainty**   B.   **Effects of exercising cost**

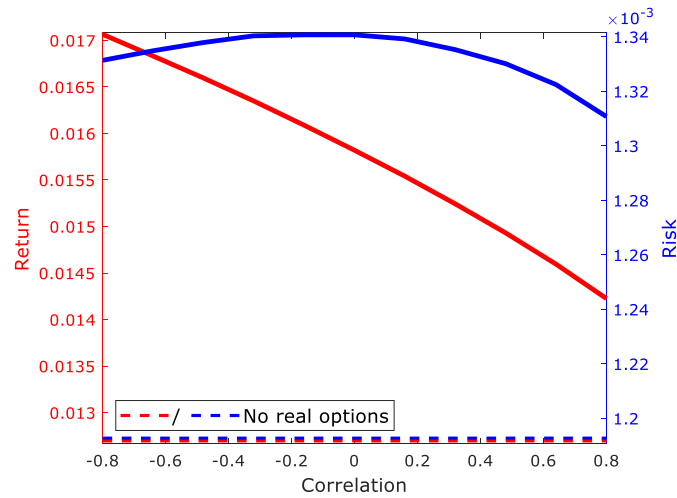**Figure 3. Option to alter operating scale**

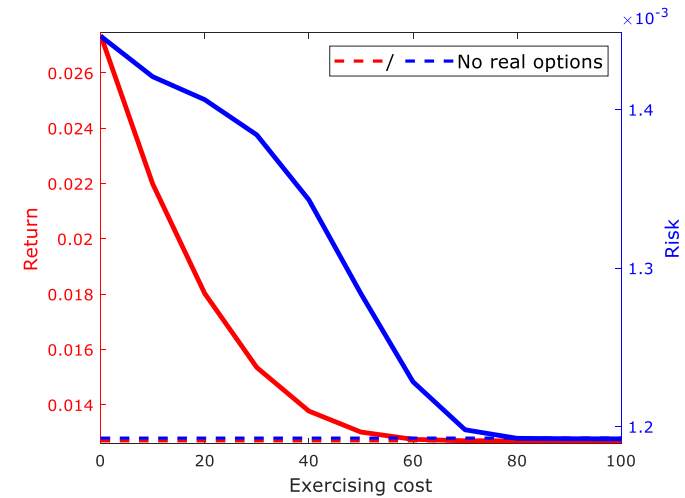**Real Options: Added Return *versus* Added Risk**

A.   **Effects of uncertainty (origin)**

B.   **Effects of uncertainty(destination)**

C.   **Effects of correlation**

D.   **Effects of exercising cost**

Figure 4. Option to switch outputs