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Using option-games to describe strategy selection of technology investment in the green supply chain

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Abstract

In the context of green supply chain management that involves environmental risks and carbon emissions reduction, investment in new green technology of production, delivery, and waste disposal is unavoidable. With high uncertainty of green product demand as driver of those investment and huge amount of fund required, made decision about them become complicated problems. The application of the "tolerability of risk" concept will be used as basis for determining the extent of environmental risk and carbon emission reduction. In this paper, we propose a combination of real options and game theory to describe manufacturer strategy selection of technology investment to reduce life cycle environmental risk of hazardous materials and carbon emission. We hypothesize that manufacturers will try to reduce environmental risk and carbon emission as much as economical profit is achievable. A case example is provided to demonstrate an application of the model.

Keywords: green supply chain management, technology investment, real options, game theory

1 Introduction

Since early 1980s, supply chain management (SCM) problems and challenges have attracted academic community to do research and develop new model. They cover a range of control and planning applications relating to material selections, production, transportation, distribution etc, as well as the potential collaboration among manufacturers, retailers and customers (Blanchard, 2007; Harrison & Hoek, 2008). With the introduction of a low carbon economy and green GDP, there has been growing concern about theory and practice of green supply chain (GSC) among scholars and market administrators (Karakayali et al., 2007; Saadany and Jaber, 2010).

Green supply chain management (GSCM) is a management approach that takes environmental impact and resource efficiency into overall consideration of the entire supply chain. GSCM can be formally defined as a series of regulations and interventions in the supply chain achieved by attempting to minimize the environmental impact from the suppliers to the end users (Basu & Wright, 2008). According to Zhang & Liu (2012), GSCM able to strengthens the learning and cooperation among various enterprises on the supply chain, improves the green level of the entire supply chain, and realizes the organization and coordination management of green supply chain by way of supplier training, environment forum, green promotion and related technical support.

There are several environmental concerns in the context of GSCM. One of the major is the detoxification of industrial pollutants with clean technologies (Wang, 2009), since many common industrial materials used in manufactured products can be considered harmful or hazardous to the environment. In addition, carbon footprint within supply chain becomes indicator of the public's acceptance of the product. Decarbonization has become a significant challenge to the supply chain management by requiring consideration be paid to life cycle stages beyond the supply chain and consumer (Zhao et.al, 2012).

Investment in clean technologies to purifies industrial pollutant and also reduces carbon footprint level into public acceptable level is one of capital-intensive operation. Traditional methods in supporting investment decision (NPV), do not properly take account for the flexibility inherent in investment decisions to launch them at the right time and right scale. Real-option analysis presents an alternative method since it takes into account the managerial flexibility of responding to a change or new situation in business condition (Trigeorgis, 1996). Some of the business areas such as automotive and telecommunication industries, the situation is characterized as an oligopoly competition where there are only a few company present who know each other's activities and take into account the other competitors actions (Angelou & Economides, 2009).

The goal of this paper is to combine real options and game theory to describe manufacturer strategy selection of technology investment to reduce life cycle environmental risk of hazardous materials and carbon emission. The paper is organized as follows. Section 2 presents literature survey of real options and games theory together with its possible implementation at green supply chain. Section 3 shows analysis framework and formulation of the option-games for modeling technology investment on green supply chain. Section 4 applies the proposed models and methodology in a real business study. Finally, section 5 summaries and conclude the result.

2 Real options and game theory

Technology investments have unique characteristic where NPV (net present value) analysis does not capture the complete picture for several reason (Wu, 2012). First, investing in technology is a high-risk process that requires significant capital investment, and uncertainty plays a key role in decision-making. In contrast with NPV, an option gives its holder the right, but not the obligation, to buy or sell an underlying asset in the future. Option pricing theory could be applied to real assets and non-financial investments. As real options are derived from financial options, the initial phase of an investment project is implicitly equivalent to buying an option.

Trigeorgis (1996) provided an in-depth review and examples on different ROs, one of them is the option to delay investment or called option to defer. This option is crucially affected by the actions of competitor firms where delay by one firm is liable to result in its being preempted. If preemption occurs then the first firm's investment opportunity value is likely to be reduced. It is necessary to understand strategic interactions between firms in the market and so predict the behavior of one's rivals to judge whether a firm has the ability to delay investment (Angelou, 2009). One possible method to understand strategic interaction and behavior between two players is game theory.

Game theory analysis provides information on how players can determine their optimal strategies taking into account the expected behavior of the competitors. In case of green supply chain, the players can be manufacturer who willing to produce green product and process by new technology investment. Since awareness of the customer toward green product is increasing recently, they hope able to increase their market share. In order to formulate game with perfect information, it is necessary that the players know or at least assume what the competitors will do or will not do. In this paper, we focus on the option to defer investment and assume that the game does not contain a direct coordination of the players.

Game theory enrich real options model by introduction of strategic competition and emphasis flexibility versus commitment trade off. On the other hand, real options create new opportunities relative to competition from investment project by introducing dissimilar characteristic of competitors (Angelou, 2009).

3 Options games formulation

3.1 Tolerability of risk

In the context of GSCM, there are two main issues as mentioned earlier such as environmental risk and carbon emission. They need to be design, controlled and managed from early stage of product development. In order to understand the level of risk and carbon emission, it is necessary to set out certain criteria to determine acceptability levels (Bouder et al, 2007). One of the framework that can be made as a judgments whether society should accept the risk and carbon emission is the principle of tolerability of risk as shown at Figure 1 (HSE, 1988). There are three regions at that framework such as: intolerable region, tolerable region, and acceptable region. In case of acceptable region, there is a requirement to demonstrate the risk is "as low as reasonably practicable (ALARP)" where reducing the level of risk further or to accept the existing level of risk can be judged on the grounds of the risk levels and the costs associated with controlling the risk (Fuller & Vassie, 2004).

3.2 Game formulation

In this paper, it is considered only duopoly case between two manufacturers competing on producing green product and faces an investment opportunity that is treated as an option. Each player tries to maximize its payoff during one period of time. The game end when either one or both players do investment or loose their opportunity. According to the player action, there are two possible decisions in this game such as simultaneous decision game and sequential decision game, which lead to two possible equilibrium such as leader-follower equilibrium and simultaneous investment equilibrium as shown at Figure 2.

Each player has to decide either to invest (I) or to defer (D) technology investment to maximize expected pay-off. Exercising options is not conducted randomly; rather they do based on some rational decisions. In simultaneous decision game, where both players invest or defer without observing each other decisions, they will split the market according to Nash-Cournot equilibrium. On the other hand, if one manufacturer invests first and the other does it later (sequential decision game), their payoff will be determined through a Stackelberg leader-follower equilibrium (Angelou, 2009).

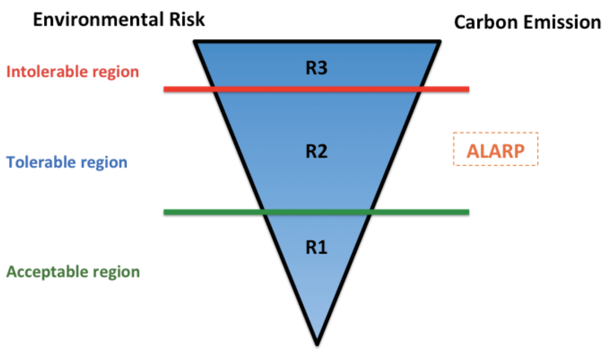

Figure 1. Tolerability of risk concept

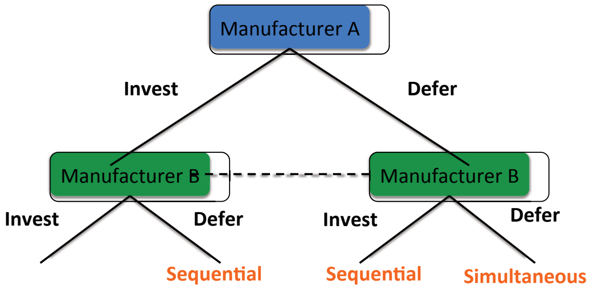

Figure 2. Game design

3.3 Payoff function

We assume that payoff of the manufacturer within the supply chain involves in the game is evaluated based on the current profit (before investment) of the manufacturer (P) and the effects of decision concerning investment in green product technologies. Equation 1 expressed basic payoff function for green supply chain technology investment.

$$PF = Max(P + AP + MS - OC - ER - CE, 0) \quad (1)$$

$$ER = \Pr \times N \times Cr \quad (2)$$

$$CE = Gf \times Hd \times Ct \quad (3)$$

The variables involves in equation 1 are as follows:

- PF : payoff function
- P : profit before investment
- AP : expected additional profit after investment
- ER : environmental risk cost for each region
- CE : carbon emission cost for each region
- OC : exercise cost of investment
- MS : expected market share

Current profit (P) is the profit that manufacturer achieved before investing into new technology for producing green product. After investment, manufacturer expects to have additional profit (AP) due to their success in increasing market share (MS) by acquiring new customer who passionate in green products. The inherent risk cost of the manufacturer supply chain (ER) can be measured by multiplying the consequence (N) by its corresponding probability (Pr) and cost factor (Cr) in particular hazard scenario (Okabe & Ohtani, 2009), as expressed at equation (2). The number of fatalities resulting from environmental accidents or other adverse events attributed to the supply chain is taken as the consequence (N). Carbon emission cost (CE) can be measured based on an approach proposed by DEFRA (2009) where green house gases emission factor (Gf) multiplied by an activity data factor (Hd) and cost factor (Ct). In term of supply chain, the activity data factor reflects energy consumption in the process of production, transportation, and annual volume of various waste materials generated.

As mentioned previously that each manufacturer has an option to invest or to defer investment. If they are at acceptable region, investment is no longer necessary. On the other hand, manufacturer at tolerable region or intolerable region, they have two choices whether to invest or defer the investment. Depend on the number of investment, their region will be move to better ones e.g. tolerable to acceptable, intolerable to tolerable or acceptable. The complete payoff set of manufacturer strategies are shown at Appendix 1. This payoff matrix is appropriate to be used when at the initial stage; there is more than one company interested in investment. It is also assume that time horizon is only one.

It is assume that manufacturer who did investment will get benefit of reduction environmental risk and carbon emission, and also they will get additional profit and market share. From the payoff table, we can see that manufacturer tend to invest new technology to reduce their environmental risk and carbon emission. The notation for each variable is as follows:

- r1, r2, r3: reduction factor of environmental risk for manufacturer at acceptable, tolerable and intolerable level
- f1, f2, f3: reduction factor of carbon emission for manufacturer at acceptable, tolerable and intolerable level
- OC1, OC2, OC3: exercise cost of carbon emission investment from tolerable to acceptable, intolerable to acceptable, and intolerable to tolerable
- OC4, OC5, OC6: exercise cost of environmental risk investment from tolerable to acceptable, intolerable to acceptable, and intolerable to tolerable
- p : reduction factor of additional profit
- m : reduction factor of market share

3.4 Two stage model

Technology investment in green supply chain mostly conducted in two stages where at the first stage pioneer manufacturer have an option whether to invest or to defer new technology of green product according to their current region. After investment successful, which profit and market share increase, other competitor tries to follow an investment. According to Smit (2004), at second stage pioneer manufacturer can take *proprietary* or *shared* strategy where competitor can take *contrarian* or *reciprocating* strategy. Figure 3 illustrate two stages development game model.

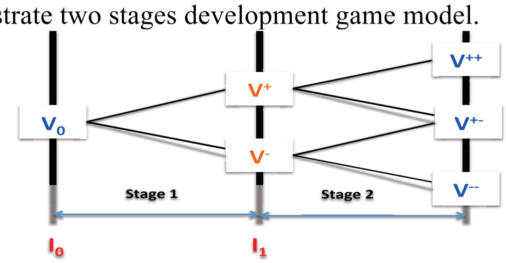

Figure 3. Two stage development game

4 Case study

In late 2005, Wal-Mart announce their new sustainability initiative to make a positive impact and greatly reduce the impact of Wal-Mart on the environment in order to become the "most competitive and innovative company in the world" (Plambeck, 2007). There are three ambitious goals such as:

1. Be supplied 100 percent by renewable energy in the near future
2. Create zero waste
3. Sell products that sustain Wal-Mart's resources and the environment

In order to achieve those goals, Wal-Mart needs to spend around $500 million per year.

First Stage

At the initial stage, consider the value of the project is 50% higher than their investment, up or down with binomial parameter u=1.8 and d=0.6, risk adjusted discount rate k=0.2, risk free rate=0.08, and actual probability q=0.5. Risk neutral probability is calculated as follow:

$$p = \frac{(1+0.08)-0.6}{1.8-0.6} = 0.4, 1-p = 0.6$$

Project value at favorable condition = 1.8x750=1350

Project value at unfavorable condition = 0.6x750=450

At time = 1, NPV of the investment will be

$$NPV = -I + \sum_{t=1}^{1} \frac{E(FCF_t)}{(1+k^t)} = -500 + \frac{0.5\times 1350 + 0.5\times 450}{1+0.2} = 250$$

With the managerial flexibility, there are options to invest or abandon the project. Calculation of each option is as follow:

$$C_u = Max(V^+ - I, 0) = Max(1350-500, 0) = 850(invest)$$

$$C_d = Max(V^- - I, 0) = Max(450-500, 0) = 0(abandon)$$

$$C_0 = \frac{(0.4\times 850)+(0.6\times 0)}{1+0.08} = 315$$

Value of the investment option is much higher than NPV that strengthen decision to invest.

Second Stage

At the succeeding stages, in term of proprietary R & D, the net present value of project is as follow:

$$NPV = NPV^1 + NPV^2$$

$$NPV = 250 + \left(\frac{-500}{1.08} + \frac{0.5\times 1350 + 0.5\times 450}{1.2}\right)$$

$$NPV = 250 + 287 = 537$$

Project value at favorable and unfavorable condition is as follow:

$$V^{++} = 1350\times 1.8 = 2430$$

$$V^{+-} = 1350\times 0.6 = 450\times 1.8 = 810$$

$$V^{--} = 450\times 0.6 = 270$$

Proprietary vs. contrarian

If both manufacturer willing to invest and it is assume that pioneer manufacturer (A) will capture 2/3 market share at favorable condition and preempt at unfavorable condition, the payoff are as follows:

Favorable

$$PayOffA = (\frac{2}{3}\times 1350 - 250) = 650$$

$$PayOffB = (\frac{1}{3}\times 1350 - 250) = 250$$

Unfavorable

$$PayOffA = (\frac{2}{3}\times 450 - 250) = -33$$

$$PayOffB = (\frac{1}{3}\times 450 - 250) = -17$$

If both manufacturer choose to defer and it is also assume that pioneer manufacturer (A) will capture 2/3 market share, the payoff are as follows:

Favorable

$$PayOffA = \frac{0.4\times(\frac{2}{3}\times 2430 - 250) + 0.6\times(1\times 810 - 500)}{1+0.08} = 734$$

$$PayOffB = \frac{0.4\times(\frac{1}{3}\times 2430 - 250) + 0.6\times 0}{1+0.08} = 207$$

Unfavorable

$$PayOffA = \frac{0.4\times(1\times 810 - 500) + 0.6\times 0}{1+0.08} = 115$$

$$PayOffB = \frac{0.4\times 0 + 0.6\times 0}{1+0.08} = 0$$

If either one of the manufacturer willing to invest and the other defer, the payoff are as follows:

Favorable

Payoff=1350-500=850

Unfavorable

Payoff=450-50=-50

High Demand

A \ B	Defer	Invest
Defer	(734,207)	(0,850)
Invest	(850,0)	**(650,250)**

Low Demand

A \ B	Defer	Invest
Defer	**(115,0)**	(0,-50)
Invest	(-50,0)	(-33,-17)

Proprietary vs. reciprocating

If both manufacturer willing to invest and it is assume that pioneer manufacturer (A) will capture 2/3x3/4 market share at favorable condition and preempt at unfavorable condition, while the competitor (B) will capture 2/3x3/4 market share, the payoff are as follows:

Favorable

$$PayOffA = (\frac{2}{3}\times\frac{3}{4}\times 1350 - 250) = 425$$

$$PayOffB = (\frac{1}{3}\times\frac{3}{4}\times 1350 - 250) = 87.5$$

Unfavorable

$$PayOffA = (\frac{2}{3}\times\frac{3}{4}\times 450 - 250) = -25$$

$$PayOffB = (\frac{1}{3}\times\frac{3}{4}\times 450 - 250) = -137.5$$

If both manufacturer choose to defer and it is also assume that pioneer manufacturer (A) will capture 2/3 market share, the payoff they will get in favorable and unfavorable conditions are as follows:

Favorable

$$PayOffA = \frac{0.4\times(\frac{2}{3}\times\frac{3}{4}\times 2430-250)+0.6\times(1\times 810-500)}{1+0.08} = 530$$

$$PayOffB = \frac{0.4\times(\frac{1}{3}\times\frac{3}{4}\times 2430-250)+0.6\times 0}{1+0.08} = 133$$

Unfavorable

$$PayOffA = \frac{0.4\times(1\times 810-500)+0.6\times 0}{1+0.08} = 115$$

$$PayOffB = \frac{0.4\times 0+0.6\times 0}{1+0.08} = 0$$

High Demand		B: Defer	B: Invest
A	Defer	(530,133)	(0,850)
	Invest	(850,0)	**(425,87.5)**

Low Demand		B: Defer	B: Invest
A	Defer	**(115,0)**	(0,-50)
	Invest	(-50,0)	(-25,-137.5)

Shared vs. contrarian

If both manufacturer willing to invest and it is assume that pioneer manufacturer (A) will capture 1/2 market share at favorable condition and unfavorable condition, the payoff are as follows:

Favorable

$$PayOff = (\frac{1}{2}\times 1350-250) = 425$$

Unfavorable

$$PayOff = (\frac{1}{2}\times 450-250) = -25$$

If both manufacturer choose to defer and it is also assume that pioneer manufacturer (A) will capture 2/3 market share, the payoff are as follows:

Favorable

$$PayOff = \frac{0.4\times(\frac{1}{2}\times 2430-250)+0.6\times(\frac{1}{2}\times 810-250)}{1+0.08} = 444$$

Unfavorable

$$PayOff = \frac{0.4\times(\frac{1}{2}\times 810-250)+0.6\times 0}{1+0.08} = 58$$

High Demand		B: Defer	B: Invest
A	Defer	(444,444)	(0,850)
	Invest	(850,0)	**(425,425)**

Low Demand		B: Defer	B: Invest
A	Defer	**(58,58)**	(0,-50)
	Invest	(-50,0)	(-25,-25)

Shared vs. reciprocating

If both manufacturer willing to invest and it is assume that pioneer manufacturer (A) will capture 2/3x3/4 market share at favorable condition and preempt at unfavorable condition, while the competitor (B) will capture 2/3x3/4 market share, the payoff they will get are as follows:

Favorable

$$PayOff = (\frac{1}{2}\times\frac{5}{4}\times 1350-250) = 594$$

Unfavorable

$$PayOff = (\frac{1}{2}\times\frac{5}{4}\times 450-250) = -31$$

If both manufacturer choose to defer and it is also assume that pioneer manufacturer (A) will capture 2/3 market share, the payoff they will get in favorable and unfavorable conditions are as follows:

Favorable

$$PayOff = \frac{0.4\times(\frac{1}{2}\times\frac{5}{4}\times 2430-250)+0.6\times(\frac{1}{2}\times 810-250)}{1+0.08} = 661$$

Unfavorable

$$PayOff = \frac{0.4\times(\frac{1}{2}\times\frac{5}{4}\times 810-250)+0.6\times 0}{1+0.08} = 95$$

High Demand		B: Defer	B: Invest
A	Defer	(661,661)	(0,850)
	Invest	(850,0)	**(594,594)**

Low Demand		B: Defer	B: Invest
A	Defer	**(95,95)**	(0,-50)
	Invest	(-50,0)	(-31,-31)

The game tree can be illustrated as follows:

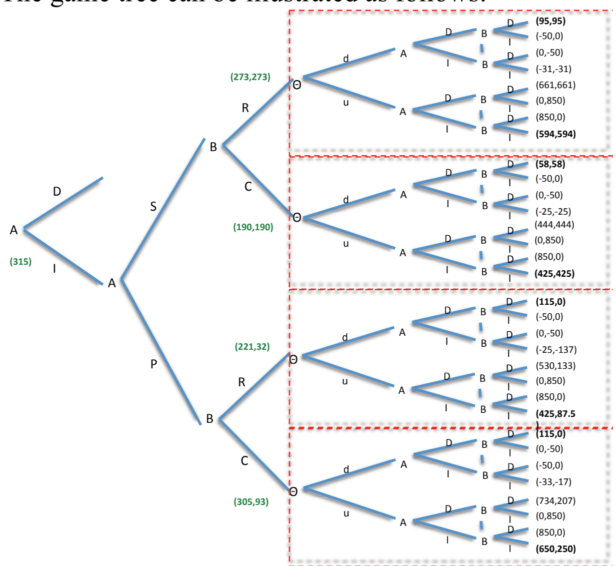

Figure 4. Game tree

5 Conclusions

The option-games model proposed in this research for analyzing strategy of the manufacturer toward environmental risk issues, has been successfully describe the strategy of manufacturer at different condition. Major factors affecting manufacturer decision have been incorporated into the model. From the two stages option-games development, it can be seen that investment into green technology is worthwhile to do and at the second stage, shared-reciprocating strategy contribute to the highest value return.

However, we recognize that there are some limitations for this option game model such as: government roles are neglected and we only analyze interaction between manufacturer at the same echelon level of supply chain.

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Appendix 1

Table 1. Payoff of the manufacturer strategies

Environment Risk		Carbon Emission					
		Acceptable	Tolerable		Intolerable		
			Invest to acceptable	Defer	Invest to acceptable	Invest to tolerable	Defer
Acceptable		P+AP+MS-(1-r1)ER-(1-f1)CE, P+AP+MS-(1-r1)ER-(1-f1)CE	P+AP+MS-(1-r1)ER-(1-f1)CE, P+AP+MS-OC1-(1-r1)ER-(1-f1)CE	P+AP+MS-(1-r1)ER-(1-f1)CE, P+(1-p)AP+(1-m)MS-(1-r1)ER-(1-f2)CE	P+AP+MS-(1-r1)ER-(1-f1)CE, P+AP+MS-OC2-(1-r1)ER-(1-f1)CE	P+AP+MS-(1-r1)ER-(1-f1)CE, P+(1-p)AP+(1-m)MS-OC3-(1-r1)ER-(1-f2)CE	P+AP+MS-(1-r1)ER-(1-f1)CE, P-(1-r1)ER-(1-f3)CE
Tolerable	Invest to acceptable	P+AP+MS-OC3-(1-r1)ER-(1-f1)CE, P+AP+MS-(1-r1)ER-(1-f1)CE	P+AP+MS-OC3-(1-r1)ER-(1-f1)CE, P+AP+MS-OC1-(1-r1)ER-(1-f1)CE	P+AP+MS-OC3-(1-r1)ER-(1-f1)CE, P+(1-p)AP+(1-m)MS-(1-r1)ER-(1-f2)CE	P+AP+MS-OC3-(1-r1)ER-(1-f1)CE, P+AP+MS-OC2-(1-r1)ER-(1-f1)CE	P+AP+MS-OC3-(1-r1)ER-(1-f1)CE, P+(1-p)AP+(1-m)MS-OC3-(1-r1)ER-(1-f2)CE	P+AP+MS-OC3-(1-r1)ER-(1-f1)CE, P-(1-r1)ER-(1-f3)CE
	Defer	P+(1-p)AP+(1-m)MS-(1-r2)ER-(1-f1)CE, P+AP+MS-(1-r1)ER-(1-f1)CE	P+(1-p)AP+(1-m)MS-(1-r2)ER-(1-f1)CE, P+AP+MS-OC1-(1-r1)ER-(1-f1)CE	P+(1-p)AP+(1-m)MS-(1-r2)ER-(1-f1)CE, P+(1-p)AP+(1-m)MS-(1-r1)ER-(1-f2)CE	P+(1-p)AP+(1-m)MS-(1-r2)ER-(1-f1)CE, P+AP+MS-OC2-(1-r1)ER-(1-f1)CE	P+(1-p)AP+(1-m)MS-(1-r2)ER-(1-f1)CE, P+(1-p)AP+(1-m)MS-OC3-(1-r1)ER-(1-f2)CE	P+(1-p)AP+(1-m)MS-(1-r2)ER-(1-f1)CE, P-(1-r1)ER-(1-f3)CE
Intolerable	Invest to acceptable	P+AP+MS-OC4-(1-r1)ER-(1-f1)CE, P+AP+MS-(1-r1)ER-(1-f1)CE	P+AP+MS-OC4-(1-r1)ER-(1-f1)CE, P+AP+MS-OC1-(1-r1)ER-(1-f1)CE	P+AP+MS-OC4-(1-r1)ER-(1-f1)CE, P+(1-p)AP+(1-m)MS-(1-r1)ER-(1-f2)CE	P+AP+MS-OC4-(1-r1)ER-(1-f1)CE, P+AP+MS-OC2-(1-r1)ER-(1-f1)CE	P+AP+MS-OC4-(1-r1)ER-(1-f1)CE, P+(1-p)AP+(1-m)MS-OC3-(1-r1)ER-(1-f2)CE	P+AP+MS-OC4-(1-r1)ER-(1-f1)CE, P-(1-r1)ER-(1-f3)CE
	Invest to tolerable	P+(1-p)AP+(1-m)MS-OC5-(1-r2)ER-(1-f1)CE, P+AP+MS-(1-r1)ER-(1-f1)CE	P+(1-p)AP+(1-m)MS-OC5-(1-r2)ER-(1-f1)CE, P+AP+MS-OC1-(1-r1)ER-(1-f1)CE	P+(1-p)AP+(1-m)MS-OC5-(1-r2)ER-(1-f1)CE, P+(1-p)AP+(1-m)MS-(1-r1)ER-(1-f2)CE	P+(1-p)AP+(1-m)MS-OC5-(1-r2)ER-(1-f1)CE, P+AP+MS-OC2-(1-r1)ER-(1-f1)CE	P+(1-p)AP+(1-m)MS-OC5-(1-r2)ER-(1-f1)CE, P+(1-p)AP+(1-m)MS-OC3-(1-r1)ER-(1-f2)CE	P+(1-p)AP+(1-m)MS-OC5-(1-r2)ER-(1-f1)CE, P-(1-r1)ER-(1-f3)CE
	Defer	P-(1-r3)ER-(1-f1)CE, P+AP+MS-(1-r1)ER-(1-f1)CE	P-(1-r3)ER-(1-f1)CE, P+AP+MS-OC1-(1-r1)ER-(1-f1)CE	P-(1-r3)ER-(1-f1)CE, P+(1-p)AP+(1-m)MS-(1-r1)ER-(1-f2)CE	P-(1-r3)ER-(1-f1)CE, P+AP+MS-OC2-(1-r1)ER-(1-f1)CE	P-(1-r3)ER-(1-f1)CE, P+(1-p)AP+(1-m)MS-OC3-(1-r1)ER-(1-f2)CE	P-(1-r3)ER-(1-f1)CE, P-(1-r1)ER-(1-f3)CE