Produto & Produção, vol. 11, n. 3, p. 59-68, out. 2010

Real options as a tool to hedge technological convergence risks in the american ethanol industry: a preliminary investigation

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Opções reais, conceito derivado de opções financeiras, é uma técnica emergente de avaliação de investimento sob incerteza. Considerando que opções financeiras são aplicadas para gestão de risco de ativos financeiros, é razoável assumir que as opções reais possam ser uma ferramenta útil para a gestão de risco operacional. Todavia, opções reais são, na maioria dos casos, aplicadas para avaliar investimentos. A maioria dos produtores de etanol nos EUA usam milho como principal matéria-prima. No entanto, outras tecnologias competidoras, que usam cana de açúcar e celulose, também estão disponíveis. Portanto, existe risco de convergência tecnológica nessa indústria. O objetivo deste artigo é investigar o uso de opções reais como ferramenta para gerir risco de convergência tecnológica. A indústria americana de etanol é o caso base para desenvolver essa investigação preliminar.

Palavras- chave: Opções reais, tecnologia, *hedge.*

Real options, which derivate from the concept of financial options, is an emerging technique to evaluate investment under uncertainty. Given that financial options are applied to financial assets risk management, it is reasonable to assume that real options could be a useful tool to manage operational risks. However, the real options approach is mostly applied to evaluate investments. The majority of Ethanol producers in the United States produce such product based on corn. Nevertheless, other competing technologies are available such as sugar-cane and cellulosic. Thus, there is a technological convergence risk is this industry. This paper's main goal is to explore the use of real options as a tool to manage technological convergence risk. The American ethanol industry is the baseline case to this preliminary investigation.

Keywords: Real options, technology, hedge.

1 Introduction

The high volatility of oil prices, as shown in Figure 1, is providing opportunities for the ethanol industry (Du & Hayes, 2008). The question on the real threat of ethanol as an alternative to gasoline is still unanswered. Such issue will basically depend on governmental policies and automobile engines modification in order to turn ethanol into an established fuel (Sklo *et al.,* 2007). However, ethanol production has been showing a positive evolution. In 2006, for example, production reached 13.5 billion gallons with the USA and Brazil as leading producers, and China and India rapidly increasing their production (RFA, 2007).

In 2007 there were 96 different corporations producing ethanol in the US, totalizing 110 different facilities; there were also 77 new facilities under construction (RFA, 2007). Almost all of those facilities produced corn-based ethanol. However, corn-based technology is not the only one available to produce ethanol; at least two other production technologies compete with it: sugar-cane and cellulosic based ethanol.

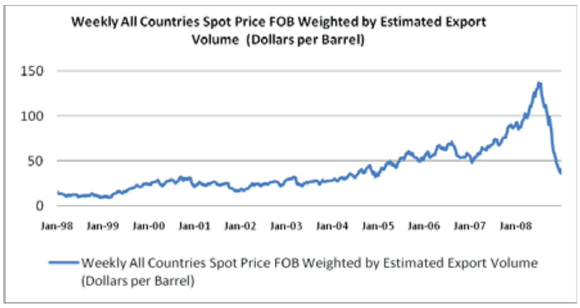

Figure 1 – Oil prices from 1998 to 2008
Source: www.energycapital.com, 2009

The sugar-cane based ethanol experience in Brazil is probably the most successful case of an ethanol program in the world. Such success was enabled not only by the PROALCOOL program but also by high oil prices. Since the 1970s ethanol consumption in Brazil is growing, helping to substantially increase its productivity (MOREIRA & GOLDEMBERG, 1999; GOLDEMBERG *et al.,* 2004).

"the corn ethanol will always be used as a feedstock for ethanol production, but in the near future it will be joined by cellulosic material as a major feedstock of ethanol production". Agricultural waste, garbage, and municipal waste may also become other sources of ethanol production (RFA, 2007).

The aim of the paper is not to detail all production technology possibilities for the ethanol industry. However, with the brief discussion presented above it is clear the high level of uncertainty on the definition of the best technology for this industry. Hence, some questions arise: Are those United States ethanol companies comfortable in leveraging all its ethanol production on corn? Should not they aim at a broader portfolio of technologies? These two questions are closely related to the core of this paper, which is to introduce the application of Real Options as an approach to manage technological convergence risk.

Initially, risk management applied to financial theory will be investigated; more specifically derivatives and real options are discussed. During the development of the paper it will be shown that the real options approach may help to manage technological convergence risk. Indeed, the real options approach helps answering, although not totally solving the questions proposed earlier. Insights on how Real Options could be applied to manage technological risk using as an example from the United States ethanol industry are given along the paper.

The rest of this paper is organized as follows. Section 2 provides a brief discussion on derivatives, options and risk management. Real options and capital investment under uncertainty are discussed in Section 3. In Section 4 the concept of real options and operational hedging strategy is reviewed. An example of the application of financial options to hedge commodity risks is presented in Section 5. Later, a discussion on the use of real options to hedge technological convergence risk in the American ethanol industry is presented, followed by the implications of this approach to United States ethanol corporations. Finally, the last section states the conclusions and future research opportunities.

2 Derivatives, options and risk management: an overview

After thirty years since Black & Scholes (1973) and Merton (1973) published the Nobel Prize winning work on Option Pricing, the derivatives market has faced a considerable increase in over-the-counter and formal exchanges (BIS, 2005). Forward, futures, swaps and options are the most common types of derivatives, and many studies present their use for managing risks in different applications; for example: currency (ADLER & DUMAS, 1984; GECZY ET AL. 1997; ALLAYANNIS & OFEK, 2001; WONG & YICK, 2004), interest rates and credit (GORTON & ROSEN, 1995; NEAL, 1996; ADEDEJI & BAKER, 2002; BIERWAG & FOOLAD, 2006), commodity risks (VELD-MERKOULOVA & ROON, 2003; TOMEK & PETERSON, 2001; TUFANO, 1996; PETERSON & LEUTHOLD, 1987), and other applications (CARMONA & DURRLEMAN, 2003; GASTINEAU & MARGOLIS, 1994; KOSKI & PONTIFF, 1999; TURVEY, 2001).

Companies that seek to reduce the risk exposure of some asset may buy some instrument in the derivatives market to hedge its risks (CHANCE, 2004). Not only financial but also non-financial institutions are able to hedge their position with a derivative. Bartram (2006) states that from 15 to 25 % of the firms out of the financial sector use options as a risk management tool. This strategy will be even more effective if the company can leverage these real options on its existing capabilities; for example, reputation and human resources.

The main objective of derivatives application by non-financial institutions is to better manage risks (BODNAR *et al.,* 1998). However, one may ask how has such theory been applied to real assets. The following section discusses real options.

3 Real options and capital investment under uncertainty

Myers (1977) was the first to introduce the concept of options in real assets (real options) throughout the existence of growth opportunities based on current projects. In 1984, the same author (MYERS, 1984) presented a discussion on the gap between financial theory and strategic planning. His work pointed out some issues regarding the Discounted Cash Flow (DCF): the inflexibility of the method, the problem of not capturing the growth value opportunities and the option to abandon a project, and the application of internal rate of return (IRR) to rank projects.

Currently, given the constraints of DCF in uncertain environments, a broad discussion about new capital investment techniques is under development. There are books dedicated specifically to this issue (MUN, 2002; AMRAN & KULATILAKA, 1999; SMIT & TRIGEORGIS, 2004; DIXIT & PINDYCK, 1994). Some improvements have been applied to DCF methods in order to increase their performance, through the development of APV – Adjusted Present Value, as a competitor to the use of WACC (Weighted Average Cost of Capital) – (MYERS, 1974; LUEHRMAN, 1997b; BRICK & WEAVER, 1984; CIGOLA & PECCATI, 2005). Furthermore, stochastic models have been replacing deterministic models to handle cash-flow uncertainty (DIXIT & PINDYCK, 1994).

However, the most prominent approach to evaluate capital investment problems under uncertainty seems to be the real options. The issues of irreversibility, not delay ability, value creation through growth opportunities, managerial flexibility are, in some aspects, faced by the real options approach (DIXIT & PINDYCK, 1994; LUEHRMAN, 1997a; PARK & HERATH, 2000; MILLER & PARK, 2002).

Given all the promises of real options, the approach has been applied in a wide range of industrial segments. Miller & Park (2002) present a review of real options applications in biotechnology, manufacturing/inventory, natural resources, research and development (R&D), stock valuation, strategy and technology.

The main underlying concept of real options applications in capital investment under uncertainty is that managers do not act in a static manner managing a project. If the project is not performing well, it may be changed or even abandoned. Flexibility is captured and measured by real options (TRIGEORGIS, 1993).

During the last decades, the applications and developments of real options theory have been dependent on the development of financial options price theory (TRIGEORGIS, 1993). On one hand, for the underlying asset of a financial option (some asset that is being traded in the market) there is often data available for more than a decade. On the other, for the real options in general, there is a lack of historical data. Such drawback makes real options value estimation a difficult task.

It is reasonable to assume that if real options derive from financial options, some (or most) of the theory to evaluate financial options has been applied to evaluate real options. Hence, such is the discussion core in the literature related to real options. Black & Scholes (1973) and Merton (1973), with their Nobel Prize winning formula for continuous time calculation of options, and also Cox *et al.* (1979) with their simplified model considering the calculation of the option on discrete events, are maybe the most used models. However, many other more specific models have been applied; for example, Margrabe (1978) with the formula to exchange risk assets, and Cox & Ross (1976) with the technique to model jumps and diffusion process.

4 Real options and the operational hedging strategy

Financial options have been applied as an instrument to manage risks during the last decades. However, the literature in real options is very focused on the application of real options as an investment analysis technique, and not as a risk management one (JORION, 2005).

Nevertheless, real options could be used as a risk management technique as it is a financial option. One main feature of an option is that with low investment it is possible to hedge a significant asset. However, the derivatives market sometimes is not the best way to hedge some types of risks (AABO & SIMKINS, 2005): in the medium and long-term horizon such market tend not to be very efficient in hedging operational risks (AABO &SIMKINS, 2005).

Triantis (2000) provides a risk qualification faced by companies. Technological risks may include research and development outcome risks, implementing new technology, production breakdown and defective products. Economic risks are related to material and labor costs, product demand uncertainty, output price risk and market share risks. Interest rate risk, commodity price risk, currency rate risk and security holdings risk could be considered as financial risks. Performance risks may be exemplified as subcontractor performance, credit risk of contract counterparties and judicial risk. Legal/regulatory risks are related to tax law changes, political regime switches or insurrection, and environmental regulation changes and expropriation.

Hence, financial options can hedge financial risks and some economic and performance risks but it cannot deal, for instance, with technological risks (at least in the medium and long range). Triantis (2000) also points out that in a long-term international project exposed to a high volatile exchange rate risk, it may be less expensive to hedge this risk with real options than with financial options. Such strategy will be even more effective if the company can leverage these real options on its existing capabilities; for example, reputation and human resources.

Companies facing some financial risk can go to the market to buy some financial option (or another kind of derivative) to hedge their risk. Bond managers can buy some interest rate options depending on the market condition to maintain their portfolio value. Equity managers can buy some kind of stock options to manage their portfolio risk. Farmers and industrial producers can go to the commodity market to decrease the volatility of their revenues or cost of commodities. Under the same context, can a United States ethanol corporation create real options to face some kind of technological risk?

Indeed, it is possible to consider real options as a hedging instrument. Some studies have presented real options as an alternative to manage global operational risks. The application of the real options approach as a risk management strategy has been addressed in some studies (AABO & SIMKNS, 2005; CARTERA *et al.*, 2003; PANTZALIS, 2001; CAPEL, 1997), since real options maintain the upside profit possibility limiting the downside loss. However, these applications are limited to currency exposure risks.

Aabo & Simkins (2005) point out that for exchange rate risk management the main relation between financial options and real options is that the first one is effective in the short-term and the second in the long-term. One of the main reasons for that is that, because in the long-term some of the physical transactions may not perform as planned, the company's position in the financial option contract might become speculative.

Another application uses real options to hedge currency exposure based on the global flexibility of a company (CARTERA *et al.,* 2003). Shifting input option may be created if the company is able to exchange a local supplier for a foreign one (or vice-versa), depending on the current exchange rate. Shifting production locations or factors of production is an option if a company has has facilities in more than one location (country). Inter and intra-country new product growth options are possibilities when a company acquires the option to expand in case the market in a foreign country becomes good.

Mello *et al.* (1995) proposed a model integrating operational flexibility and financial hedging in a currency risk environment. Kogut & Kulatilaka (1994) showed that operational flexibility has value for companies that operate globally, since the exchange rate volatility is high. The authors also provided two options that are generated when companies invest in foreign countries: *within country* growth option and *across country* operating flexibility.

Raynor (2002) introduced a concept known as *option-based diversification.* Such approach works as an insurance that investors can create investing in portfolios of developed firms. The author states that it is very important for companies in a high turbulent environment to hedge some kind of convergence phenomena that might occur. This particular diversification does not create value, but it hedges some risks that the company might face. This is a strategic insurance, as stated: "options based diversification is a response to unpredictable changes in industry boundaries".

In the current paper we explore the use of real options to hedge technological convergence for the American ethanol industry. The study presents two main contributions to the real options literature: (*i*) introduction of the concept of hedging with real options in the presence of technology convergence risk, and (*ii*) a qualitative case discussion of this concept.

In the next section we present an example of the use of financial options to hedge commodity risks. In section 6 we discuss the use of real options to hedge technological uncertainty in the United States ethanol industry.

5 Application of financial options to hedge commodity risk: an example

This section presents an example of how to hedge commodity risks with financial options. The example will support the development of a qualitative model for hedging production technology risks in the US ethanol industry with real options. Other examples of financial hedging may be found in some publications such as Hull (2006), Chance (2004), Kolb (2005) and Jorion (2005).

In this section's case an ethanol producer (Producer A) is concerned about some increase in the corn price. Producer A has a contract with fixed ethanol price to be delivered in 3 months. In order to maintain the contract's profit the corn price (corn is the feedstock used to produce ethanol) should not increase. To lock the price, Producer A decides to buy corn call options to insure its position as a buyer of corn. It is assumed (to simplify the example) that the option will be held until maturity, when it will be exercised. Hence, it is not necessary to apply any sensitivity with the use of Greeks for this option.

It is important to emphasize that Producer A is seeking to hedge because there is risk of increase in the corn price, which would decrease the company's spark-spread margin (margin between the price of the ethanol and the price of the corn).

This is the information related to the transaction that the company wants to hedge: (*i*) 26.000 gallons of ethanol, (*ii*) Producer A's productivity is 2.6 gallons per bushel of corn, (*iii*) a contract has to be delivered in 3 months and the producer wants to guarantee today's spot price, (*iv*) today's spot price is $2.20 per bushel, (*vi*) three month call options on corn is $0.08 per bushel with the strike price of $2.20, and (*vii*) one contract of option is for 5,000 bushels of corn.

Under this scenario, it is possible to define the cash leg (information about the asset that needs to be hedged) and the hedge leg (information about the asset that will hedge the cash leg) for Producer A.

To define the Cash Leg it is necessary to calculate the quantity of corn that will be used in this contract. Such quantity is calculated in Equation (1). The strike price of the option is $ 2.20 per bushel.

$$Quantity\ of\ Corn = \frac{Volume\ of\ Ethanol\ (Gallons)}{Productivity(Gallons/Bushel)} = \frac{26{,}000}{2.6} = 10{,}000\ Bushels \quad (1)$$

Once the cash leg is known, the hedge leg may be defined. Given that it is necessary to hedge 10,000 bushels of corn and each option contract hedges 5,000 bushels, Producer A will have to buy 2 call options. Each Option costs $400.00; hence Producer A will spend $800.00. This is the position that Producer A will take to hedge its asset in time zero (t_0).

Independently of the corn price variation Producer A will be guaranteed to buy corn for at most $2.20 per bushel, plus the option price. Two scenarios will be analyzed in the next two sections: in the first scenario corn price will increase; in the second, it will decrease.

5.1 Scenario I: corn price rises

In this scenario the spot price of the corn increases to $2.60 per bushel. The option is deeply on the money (actual price greater than the strike price), so Producer A will exercise the option. Table 1 explains the cash leg loss and the hedge leg profit.

Table 1 – Net Position for Scenario I

Cash Leg	Hedge Leg
Lose = ($2.60 – $2.20)*10,000 = $4000	Exercise the option and realize a profit. Profit = ($2.60 – $2.20)*10,000 = $4000
Price of the Option per Bushel = $4000/(5000 Bushels) = $0.08/Bushel	
Corn Net Cost = $2.20 + $0.08 (Option price per Bushel)= $2.28	

5.2 Scenario II: corn price falls

Under Scenario II, the spot price of the corn falls to $2.00 per bushel. The option is out of the money (the strike price is greater than the actual price), so Producer

A will not exercise the option. In Table 2 the profit in the cash leg and the lost in the hedge leg is explained.

Table 2 – Net Position for Scenario II

Cash Leg	Hedge Leg
Profit = (2.20 - 2.00) * 10,000 = $ 2000	Do not exercise the option. Cost of the options = $800
Price of the Option per Bushel = $4000/(5000 Bushels) = $0.08/Bushel	
Net Cost of the Corn = $2.00 + $0.08 (Option price per Bushel) = $2.08	

Buying the options, Producer A is hedged against corn price volatility. If the price increases the company will have to pay $2.20 plus the option premium; if it drops, it will pay the lower price plus the option premium. Basically, Producer A is hedged against corn price volatility, since it is maintaining part of the downsize gain, however reducing the upside risk. These two situations summarize the idea of using financial options in commodity risks management. Figure 2 presents a sensitivity analysis combining corn price and the result obtained with the hedging. It is possible to observe that the option has the cost of $0.08 per bushel up to a corn price of $2.00; then it starts to increase. The option cost reaches zero when the corn price is $2.28, and increases to $0.32 if the corn price rises to $2.6 per bushel.

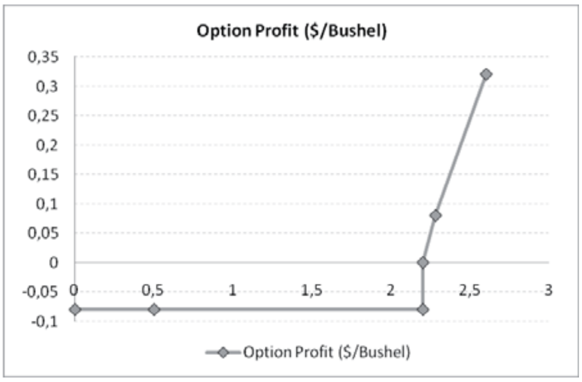

Figure 2 – Sensitivity graph relating corn price and option result

6 The application of real options to hedge production technological risk in the United States ethanol industry

The example of Producer A is a simple way to address the reasons behind firms hedge. Therefore, by the time a business is facing a financial risk that can threat its profitability, derivatives market can be a possible insurance source.

Financial hedging is, in general, used for short-term insurance of operational risks. In the case of Producer A, it would be very expensive to apply a commodity hedge for a long-term horizon. Further, long-term hedging with financial options can be very expensive for the company, since it makes difficult to control the output (ethanol quantity to be sold) in the long term. Such output risk may cause the company to change its hedging position to a pure speculative one.

The concept of hedging for industries threatened by a technological convergence risk is also discussed here. The risk of a technology becoming obsolete is basically follows the risk concept of a commodity increasing or decreasing its price. If a corporation is facing a technological convergence risk, it must try to hedge its position against the new technology. We illustrate this concept considering Corporation C as a player in the ethanol industry in the United States. Such Corporation relies on the following features: (i) 20 facilities of 30 MGPY each (Million Gallons per Year) spread across the country; (ii) presents a very organized distribution network to its retailers; (iii) sold 90% of its capacity last year; (iv) uses corn-based ethanol technology; (v) presents an overall market value of 1 billion dollars.

Corporation C is a quite considerable asset, but it is totally based on a single technology. Furthermore, the corn-based industry assumes a considerable risk in terms of what will be the best technology to produce ethanol in the future. Brazil's technology is sugar-cane based, and now United States and Brazil are developing cellulosic-based ethanol. The cellulosic ethanol is obtained from ethanol with cellulosic materials. Yacobucci (2006) states that "*Cellulosic Materials include "low"-value waste products such as recycled paper and rice hulls, or dedicated fuel crops, such as switch grass and fast growing trees*".

On the time frame of such scenario, corn ethanol was the main technology to produce ethanol in the US (USDA, 2006). However, cellulosic ethanol can quickly become the best technology, thus threatening Corporation C. The sugar-cane technology will not be considered, so the focus will be on corn and cellulosic ethanol technologies.

Alternatively, Corporation C may take a high bet on the existing corn ethanol technology and ignore the cellulosic ethanol technology. That means not considering the potential increase in corn price in the example of the financial hedging (Section 5). If the corn price remains the same or declines, it becomes a good deal; however, rising corn prices would shrink company's profitability. Thus, Corporation C is recommended to perform "low" investments in R&D related to cellulosic ethanol in order to guarantee its long-term position in the market.

"Low" investments in R&D in cellulosic ethanol can be seen as a real option that hedges the company's market value, even if the value lost in the cash leg is not totally offset by the hedge leg. Such investment becomes an option since the total value to be invested is small compared to market value of the company.

A Financial Option is a highly leveraged financial instrument; a very "low" investment can generate a significant amount of cash. The real option proposed (R&D option) is also highly leveraged, since it guarantees (or at least partially guarantees) the market value of Corporation C. Such "low" investment can be leveraged in the business structure, since the company relies on a solidly built supply chain and established brand. It is important to emphasize we are not proposing a massive investment in the cellulosic ethanol technology, but instead proposing "low" investments that are a sequence of real options.

As referred in the example in Section 5, it is possible to define cash and a hedge leg for Corporation C. In the technology hedging example, the cash leg hedges the company market value of 1 billion dollars, and the hedge leg would consist of investments in R&D of cellulosic ethanol.

We emphasize our proposal of Company C investing "low" in R&D, since there are other companies intensively investing in this technology (probably due to their better knowledge on that technology). The idea is to provide Company C with the option of making significant investments in cellulosic ethanol in case that technology proves to be more effective than corn ethanol. Figure 3 depicts a proposed framework of hedging technological convergence risk for the ethanol industry.

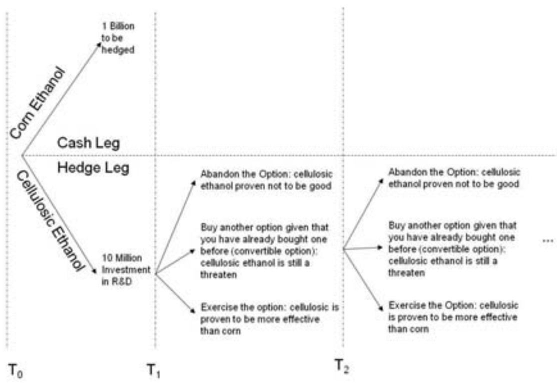

Figure 3 – Real options hedging framework proposed
Source: Author's Analysis

There are three possible strategies to be adopted by Corporation C at T1 (time 1) and T2 (time 2): Abandon the Option, Buy another Option, and Exercise the Option. We discuss each strategy in next sections.

6.1 Corporation C abandons the option

If it is proven that the cellulosic technology is worse than the existing corn technology, Corporation C will not exercise the option of investing more in cellulosic ethanol. Basically, Corporation C will shut down its R&D in cellulosic ethanol. The closing down decision could be taken in T1 (time 1) or T2 (time 2).

6.2 Corporation C buys another option

Corporation C can decide to invest in cellulosic ethanol R&D if it remains a threat to corn. This decision must be taken if neither corn nor cellulosic are proven to be the best technology to produce ethanol. This works as convertible option on another option, since one is buying option 2 (at T1 or T2) because option 1 gives this opportunity. Obviously, such a company could buy an option at time 2 without option 1, but it would probably be a more expensive option.

6.3 Corporation C exercises the option

Corporate C will make this decision if cellulosic ethanol is proven to be more effective than corn ethanol. That would imply changing the technology from corn to cellulosic, requiring Company C to invest in equipments and human resources. However, Corporation C will present significant know-how in terms of supply-chain infrastructure to retailers.

7 Implications for the american ethanol industry

Based on Section 6, it is reasonable to discuss future strategic R&D decisions for the US Ethanol Industry. Given that corn-based ethanol technology might become obsolete, companies that produce ethanol based only on corn should start investing in R&D on other technologies.

Suppose that cellulosic-based ethanol rises as a real threat; significant cellulosic-based ethanol R&D investment should be made to create real options to hedge its operational position. That would also be true for Brazilian ethanol companies strictly based on sugar-cane.

Such a problem embraces the issue of diversification versus specialization, but the approach presented in this paper is not to construct cellulosic ethanol facilities. The main point is that investment in cellulosic ethanol R&D should be leveraged for the construction of future facilities if cellulosic ethanol proves to be economically more efficient than corn.

The concept of real options as a hedging strategy insures that a corporation will be a player in the ethanol market for a long term. In addition, it is important to note that if a corn-based corporation avoided investing in cellulosic ethanol and the corn ethanol had proven to be the best technology, it would have saved investments in cellulosic ethanol R&D. However, if a corn-based corporation had not invested in cellulosic ethanol, and it was proven to be the best technology, such a corporation would have faced difficulties to maintain its participation in the market[1].

Table 3 – Summary of the policies to be adopted by ethanol companies in the US

	Risks and Benefits
Produce only with Corn	Difficult situation if cellulosic is proven to be the best feedstock. The company will probably have to acquire cellulosic technology from a competitor.
Invest only in R&D of Cellulosic	Company goes out of business if cellulosic is proven not to be efficient. To commercialize cellulosic ethanol the company will have to invest in infrastructure. Also, it can be acquired by a company which just uses corn as the feedstock if cellulosic is proven to be better.
Produce with Corn and invest in R&D related to cellulosic ethanol	If corn is proven to be the best feedstock: business as usual but loses the investment in cellulosic R&D. If cellulosic is proven to be better: use most part of the infrastructure, mostly distribution, and start production with cellulosic.

Source: Author's Analysis

Table 3 presents a summary of the policies that can be adopted by ethanol companies in the US regarding risks and benefits.

The ethanol was just a simplified example to present the concept of real option as a hedging technique. However, based on the previous discussion, some insights regarding the two questions from the introduction section could be provided: Are ethanol companies in the US comfortable in leveraging all their ethanol production on corn? Should not they aim at a broader portfolio of technologies? The core issue is not to present definitive answers on the issue. On the other hand, it seems that only corn production imposes clear risks given the current environment. Furthermore, there is no guarantee that the decision presented in Table 3 is the optimal one, but producing corn-based ethanol and investing in R&D related cellulosic ethanol tends to present lower

[1] This is exactly the same concept expressed in the financial hedging example of section 5.

risk compared to other alternatives. Finally, companies should not start immediately producing ethanol using other technologies, but they should invest in R&D of new technologies.

As future research, one must evaluate quantitatively those hedging concepts with real options. To solve such a problem, mathematical techniques as Stochastic Differential Equations and/or Dynamic Programming could be applied (BLACK & SCHOLES, 1973; CARMONA & DURRLEMAN, 2003; DIXIT & PINDYCK, 1994). Furthermore, the prices of corn, sugar-cane and ethanol will have to be modeled as stochastic parameters on the analysis.

8 Conclusion

This paper discusses basic concepts of derivatives, options and risk management, real options in capital investment and real options as an operational hedging strategy. An example of how financial options are applied to hedge commodity prices risk is presented. Based on the financial option example, a discussion of real options applications for US corn-based ethanol corporations to manage their technological risks is carried out. The main goal was to present an initial introduction to real options applications in order to manage technological convergence risk.

Despite the concept of hedging with real options, the discussion was just based on the United States Ethanol industry because it is a useful example of potential technology convergence. Also, this is a commodity based industry which, in general, relies on reliable historical price data. The availability of data makes it easier to apply methodologies as real options.

As future research, we recommend building a quantitative model to prove that real option framework as feasible. Along with the quantitative model, three issues should be considered: amount of investment to be made, time to make such investment; and value of exchanging options in a R&D project. Those are key aspects to support the sustainable development of the industry in the United States.

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