Investment in a circular economy under policy uncertainty

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Abstract

The transition towards a circular economy is high on the agenda of, and being endorsed by an increasing number of countries and / or regions in the world. For this study, our primary focus will be on circularity of plastics in the EU. Plastics are one of the most common materials used globally. Recently, action has been taken to start closing the plastics material cycle, as well as to minimize the environmental impact of the material in general. This transition towards a CE is driven by policies and achieved through private investment. Policies can either stimulate, or force investments. This study focusses on a policy compelling a firm to transition in accordance with the regulation, or to exit the market. This type of regulatory uncertain policy has not yet been researched in a real option context.

1. Introduction

The transition towards a circular economy (CE) is high on the agenda of, and being endorsed by an increasing number of countries and / or regions in the world. The main global players are: China, with its progressive CE legislation (Brooks, Wang, & Jambeck, 2018; Qi et al., 2016)[1], Japan, with well-developed waste management practices (Sasao, 2014), and the European Union (EU). For this study, our primary focus will be on circularity of plastics in the EU, mainly set out by the Plastics Strategy (EC, 2018) as well as the REACH[2] Regulation (EC, 2006). The importance of researching the circularity of plastics lies in the fact that today, plastics are one of the most common materials used globally. The ubiquity of plastics in the economy is the result of a continuing trend since the middle of the 20th century. The use of plastics has experienced a constant growth after World War II, mostly because of the unique and desirable properties of the material (OECD, 2018). Paradoxically, commonly used disposal techniques have high negative environmental impacts and cannot be regarded as being circular.

Recently, action has been taken by, among others, the EU, to start closing the plastics material cycle, as well as to minimize the environmental impact of the material in general. Examples of recent action are: (i) the European Commission's (EC) Single Use Plastics Directive which was overwhelmingly accepted[3] by the Members of the European Parliament at the end of 2018 (EC, 2019a). This directive prohibits certain plastic products to be used only once. (ii) The REACH regulation which deals with the use of certain harmful chemicals, e.g. phthalates in the production of plastics (EC, 2006). It is generally accepted that harmful chemicals slow down the transition towards circularity, e.g. health and safety difficulties arise during the recycling process. (iii) The European Strategy for Plastics in a Circular Economy (EC, 2018), which sets out targets and partly regulates the market. Because of pressure exerted by interest groups, the array of regulations for this market could grow in the future. One example is the corporate lobby, e.g. on an 'EU Action on Recycled Content Mandates for Plastics' (*A Call for EU Action on Recycled Content Mandates for Plastics*, 2018) which was later recognized and supported by the European Federation of

[1] An example is the prohibition of imports of certain plastic waste streams.
[2] Registration, Evaluation, Authorisation and Restriction of Chemicals
[3] 571 votes to 53 in favor and 34 abstentions

Waste Management and Environmental Services (FEAD) (FEAD, 2018), that could influence the EU's standpoint as well as provoke regulating policies on the mandatory use of recycled content.

The transition towards a CE is achieved through investment. Policies can either stimulate investments, e.g. subsidizing circular technology investments, or force investments. Most of the examples mentioned above are of a nature which forces the market, or could force the market in the future to make an investment by a point in time. E.g. if one's production process hasn't changed by the time the use of a certain chemical is prohibited by REACH, one will have to suspend production until the new guideline requirements are complied with. This particular type of regulation and associated forced investments, also occur outside the CE sphere. For example, some states have prohibited the use of glyphosate, a carcinogenic substance used in herbicides (VMM, 2017). Producers of herbicides therefore had to invest in order to substitute glyphosate with other chemicals. Lacking to substitute led to exclusion from the market. Not only firms, but also private persons are confronted with these kinds of regulations. Over the past decade, and continuing into the future, EU cities have been adopting Low Emission Zones (LEZ) to reduce ambient exposures to air pollution (Sandler Consultants, 2019). Typically, more polluting, older cars are de facto excluded from inner city traffic by imposing exuberant fines. Owners of affected cars find themselves with unusable cars for inner city traffic, and as a consequence, have to invest in a less polluting car to regain their private inner city auto mobility.

All cited examples, including the actions taken by the EU on a CE, push the market into a certain direction. Whether this direction is optimal remains a political discussion. Regardless of the direction towards the market is pushed, market players should, optimally, experience the same level of uncertainty, i.e. the absence of any asymmetric uncertainty (Postlewaite, 1987). However, numerous cases can be thought of in which information is asymmetrically distributed among the government and the private market.

A recurring example in the CE sphere, in which uncertainty is asymmetrically distributed among the government and the private market, is the evaluation procedure of chemicals. This procedure is carried out by the European Chemicals Agency (ECHA) as part of the REACH regulation. If chemicals are found to be of 'very high concern', they are added to the 'Candidate List of substances of very high concern for Authorisation'. Once added to this list, there exists a high degree of certainty concerning the prohibition of the particular chemical in the future[4] (ECHA, 2019). However, the exact date of the prohibition is highly uncertain. Priorities to prohibit certain chemicals before others are not purely driven by science, but influenced by politics and therefore by lobbyists. Moreover, any firm affected by a prohibition can apply for an individualized authorisation, in order to be exempted from the policy (ECHA, 2019). Typically, this exemption lasts 3, 7, or 12 years. During the entire process, including the authorization process, influential counter lobby is active. For example, chromium trioxide, a carcinogenic chemical used in the coloring of plastics has been included on the list of restricted chemicals for its application in the plastics industry. The entire process of listing chromium trioxide on this list was influenced by lobbyists (FIPRA, 2019; Hunter, 2018). The EC even institutionalizes lobby to some extent by organizing public consultations (EC, 2019b). As a consequence, firms experience uncertainty concerning the implementation date of policies.

From the foregoing examples, it is apparent that policy uncertainty is an umbrella concept for: (i) the uncertainty concerning the policy content, and (ii) the arrival of the policy, i.e. the policy implementation. Both types of policy uncertainty have a significant influence on firms and their investment decisions. In this paper we focus on the uncertain arrival time of a policy – simply referred to as policy uncertainty in the remainder of the paper. The motivation for limiting ourselves to study policy uncertainty in the form of an uncertain arrival time, and not accounting for any uncertainty on the policy content itself, is that typically the content of the policy is determined by technical constraints, especially in the case of the plastics sector, e.g. the possible use of recycled plastics is limited to a certain percentage of the total. Both policymakers and firms know these constraints, and as a consequence, policies are set within the narrow boundaries of

[4] Prohibition occurs when the chemical substance is included in the list of restricted chemicals.

these constraints. The uncertain arrival time of policies is therefore the driving factor impacting investments.

It is however unknown to which extend this uncertainty influences investments. In order to analyze how an uncertain arrival time of a policy influences investment decisions, we develop a model, accounting for policy uncertainty. We consider a monopolistic firm with the option to become more circular by undertaking an investment. The investment is assumed to be irreversible. Corporate counter lobby is taken into account, and argued to be one of the main drivers of the uncertain arrival time. Moreover, we allow the firm to observe and learn from the lobbying and its intensity. The optimal investment strategy for the firm with respect to timing can be calculated. The model is designed for applications in the plastics industry. However, we stress that applications of this model transcend the plastics industry.

The remainder of the paper is organized as follows: Section 2 provides an overview of the existing relevant literature. Section 3 will look into the model, Section 4 elucidates on the case study and is followed by the results and discussion in Section 5. Finally, Section 6 concludes on the research findings.

2. Literature

Policy uncertainty and its influence on private investments has been studied before. In general, three generations of literature can be distinguished. The first generation mainly focuses on tax policy uncertainty. One of the first academic studies on this subject is by Dixit & Pindyck (Chapter 9, 1994). They analyze the influence of a possible tax credit retraction on a fixed-sized investment. A similar, study on this matter was performed by Hassett & Metcalf (1999). In their work, they argue that the use of a Geometric Brownian Motion (GBM) to model policy uncertainty might be inferior to the use of a Poisson jump process. The results of their work show that the influence of policy uncertainty on private investments is highly dependent on how it is modeled. The advantage of a Poisson jump process, they argue, is the sharpness of the jumps. A second generation of literature regards climate change policy uncertainty. This strand of literature mainly focusses on uncertain carbon prices. Yang et al., (2008) analyze the investment in a power plant, the carbon price, they argue, follows a GBM, and influences the profitability of investments. Fuss, Szolgayova, Obersteiner, & Gusti (2008) consider an investment in carbon-saving technology under uncertain carbon prices. They consider a bifurcating carbon price, representing policy changes, and find that increased uncertainty delays investments. A third, and recent generation of literature analyzes investments in renewable energy sources. Policy uncertainty is typically regarded in the form of random provision, revision or retraction of a subsidy of support scheme. Boomsma, Meade, & Fleten (2012) use a Markov switching process to model the uncertain discrete changes between the support schemes that governments adopt for renewable energy. Boomsma & Linnerud (2015) study the uncertainty, both the retraction uncertainty and switching uncertainty, concerning support schemes for renewable energy. E.g., in case a subsidy is granted, the intensity of a subsidy is modeled with a GBM, while its retraction is modeled using a Poisson jump process. They find that policy uncertainty concerning the intensity delays investments. Uncertainty regarding the possible retraction can influence the investment timing either way. If the market believes that the decision of retraction will be applied retroactively, investments are delayed, and vice versa. Eryilmaz & Homans (2015) find that higher uncertainty regarding the granting of investment credits in the future, speeds up investments today. They considered a probability of 30% that the investment credit would be retracted, without considering re-installment in the future. A similar result is found by Chronopoulos, Hagspiel, & Fleten (2016). Policy uncertainty, in the form of a random provision or retraction of a subsidy, modeled with a Poisson jump process, speeds up investment. However, the resulting installed capacity will be lower, they argue. The investment value is found to be larger when considering step-wise investment instead of lumpy investment, the difference in value is found to be inversely proportional to the intensity of the subsidy. Likewise, in our study, we consider step-wise investment, allowing learning-effects to take place (Samadi, 2018).

In the aforementioned publications, private investors' projections on policy changes are constant over time and not updated, despite the available information on the dynamics governing policies. That is because a uniform distribution, a time homogeneous Markov or Poisson jump process, is assumed. Literature combining a real options approach with active learning is rather limited. Dalby, Gillerhaugen, Hagspiel, Leth-Olsen, & Thijssen (2018) present a good overview of the existing literature combining both. To the best of our knowledge, policy uncertainty and active learning has only been considered twice before. Dalby, Gillerhaugen, Hagspiel, Leth-Olsen, & Thijssen (2018) consider an investment option under policy uncertainty and allow for active learning via Bayesian updating. They examine how investment behavior is affected by updating a subjective belief on the timing of a subsidy revision. It is found that investors are less likely to invest when the arrival rate of a policy change increases. Bayesian updating assumes that market players receive signals, with which they update their subjective believe on policy changes. An alternative approach assumes that the policymaker is influenced by an exogenously driven dynamic, and that market players know how the policymaker is influenced. Such approach was introduced by Pawlina & Kort (2005). In their paper, the market value influences the policymaker to retract an investment subsidy. The threshold of the market value at which the subsidy is retracted, is unknown to the market players. They can, however, make projections on the retraction based on their active learning. We prefer the latter approach to active learning for our study. According to literature, European policies, as well as environmental policies can be influenced by interest groups (Cheon & Urpelainen, 2013; Dur, 2008; Oates & Portney, 2003). Policymakers experience the lobby intensity of these interest groups as an exogenous process. As mentioned in the previous paragraph, we consider step-wise investment; therewith extending the framework presented by Pawlina & Kort (2005).

The existing real options literature on policy uncertainty, both including and excluding active learning, regards the uncertainty as the intensity and / or provision (retraction) of an investment-stimulating policy. This policy typically takes the form of a subsidy, feed-in tariff, investment credit,… We extend the real option literature on policy uncertainty by taking into account a regulatory policy. This type of policy contrasts with the non-regulatory policy by compelling a firm to transition in accordance with the regulation, or to exit the market. This type of regulation is deemed to become increasingly important in a CE setting. The report by the Ellen Macarthur Foundation (2019) on the role of city governments in a CE, recognizes the importance of regulation in the transition towards a CE. After conducting an analysis assessing to what extent EU policy tools addressing products are supporting CE, the EC concluded that there is potential for further strengthening the policies ('Circular Economy Strategy - Environment - European Commission', s.a.). However, the best example of the latter is probably the progressive Chinese CE, which has been stimulated by the Chinese Government issuing regulatory policies, e.g. banning imports of certain plastic waste streams (A. L. Brooks et al., 2018). The potential of regulatory policies to enable a CE is great. Therefore, more of this kind of policies are to be expected, increasing the relevance of this work.

3. Model

We consider a risk neutral, profit maximizing firm in a continuous time setting, $t \geq 0$. The firm has the option to invest, by investing it will become circular. Market players face the risk that they will be legally required to become circular at some point in the future. Dependent on the regulation, the type of investment can differ, e.g. investing in a new production machine and / or training personnel to work with new input material. The implementation of the regulation is assumed to occur at an unknown point in time γ, after which the investment is a condicio sine qua non to produce and therefore, to have a profit flow.

After investing, extra production steps and / or higher input prices (Brooks, Hays, & Milner, 2019) and / or more production errors, etc. will influence the profit. Therefore, we assume that investing lowers the profit by an ex ante known and fixed factor δ, ($\delta \in [0,1]$). However, firms still have an incentive to invest. Lacking to invest results in zero profit after the policy implementation. Hence, there exists a trade-off between lost profits due to higher production costs before the policy implementation vs. the risk of losing all profit after the policy implementation and before investment.

We assume the production of one unit per period t, using a combination of input materials $q_{A(t)}$ and $q_{B(t)}$ ($q_{B(0)} = 0$), for which holds that $q_{A(t)} + q_{B(t)} = 1$. The fraction q_B, is the to be regulated fraction at the uncertain time ($X = \gamma$), e.g. a mandatory fraction of recycled plastics that should be used. The regulating policy will require a fraction $\overline{q_B}$ to be used after its implementation. $\overline{q_B}$ bar is known at all times, and can be reached by investment. Lacking capacity of q_B to reach $\overline{q_B}$ when $t \geq \gamma$, will lower the profit function according to the lacked capacity in q_B. Expression (1) represents the profit function:

$$\pi(t)\begin{cases} P - P\delta q_{B(t)} & if\ t < \gamma \\ \frac{q_{B(t)}}{\overline{q_B}} * (P - P\delta\overline{q_B}) & if\ t \geq \gamma \quad (q_{B(t)} \leq \overline{q_B}) \end{cases} \quad (1)$$

We consider that the required investment to reach the capacity $\overline{q_B}$ is executed in n steps ($n > 1, n \in \mathbb{N}$). It is straightforward to show that setting n equal 1 yields a trivial problem, for which the outcome of the optimal investment timing, τ, always equals $\tau = \gamma$. The total cost to adapt is lower in case many small investments are made, stretched out over time, instead of one lumpy investment. Firms investing in small steps, allow themselves to adapt without jeopardizing the entire production. Therefore, we consider step-wise investment in our model. The incentive of investing step-wise is delivered by an exponential investment cost function,

$$I(q_B) = C(e^{q_B} - 1)\eta, \quad (2)$$

where C is the investment cost per fraction q_B, and η a calibration parameter. We assume a minimal withholding time, ϑ ($\vartheta > 0$), is imposed between the investment steps. Such withholding time represents the time needed to adapt (Samadi, 2018). Allowing the minimal withholding time to be zero in a continuous time setting, yields a trivial problem comparable to the lumpy investment case.

We assume that policy makers are influenced by corporate lobby. As a consequence, the policy implementation date is assumed to be influenced by the corporate lobby. We assume that firms, who are potentially affected by the policy, can observe the exerted pressure on the policymaker and make projections on the policy implementation date. We use a similar modeling approach as proposed in the work of Pawlina & Kort (2005), in which an exogenous process, modeled as a geometric Brownian motion (GBM), exerts an influence on the consistent policy maker. We assume that corporate lobby intensity follows a GBM according to expression (3),

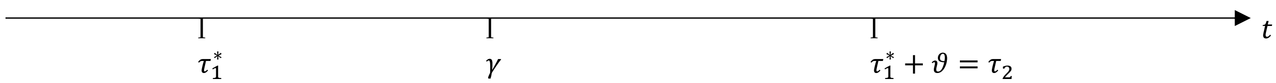
$$dL(t) = \alpha L(t)dt + \sigma L(t)dw(t), \qquad (3)$$

where: α is the deterministic drift rate, σ is the instantaneous standard deviation, and dw is the increment of a Wiener process. This motion is assumed to represent the exogenously exerted pressure on the policymaker to implement a regulation. If the exerted pressure – value of the GBM – reaches a critical level, L^*, the policy implementation follows. However, the critical level, L^*, is unknown ex ante to the market players. Similar to Pawlina & Kort (2005), we assume: (i) that only the truncated normal cumulative distribution function, $\Psi(L)$, with mean μ and variance ω^2 is known to the firm, and (ii) a consistent policy maker. If the policy has not been implemented by time φ, while $\hat{L}$ is the highest realization of the process so far, the policy will not be implemented at any time $u > \varphi$, as long as $L(t) \leq \hat{L}$ for all $t \leq u$. Note that the critique, expressed by Hassett & Metcalf (1999), on the use of a GBM to model policy uncertainty does not apply to our model. The GBM we regard, only influences the policy maker, and does not represent the policy uncertainty itself.

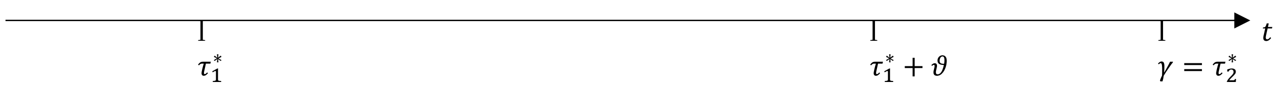
As indicated before, we consider step-wise investment. The following will elaborate on a two-step investment problem. The results of two-step investment problem can be generalized to a n-step investment problem. It is in particular the first and last investment step which are of interest, all other steps and their optimal investment timing can be derived by rewriting the problem to a two-step investment problem.

The first investment step is made at time τ_1^*, which corresponds to a lobby intensity $\bar{L}$, derived below. Two cases are to be considered, either τ_1^* precedes the policy implementation at time γ (timeline 1 and 2), or τ_1^* equals γ (timeline 3). There exists no incentive for a profit maximizing firm to postpone the first investment step beyond the policy implementation date as all uncertainty is resolved at this time. Therefore, the firm faces a now-or-never decision at time γ.

Timeline 1:



Timeline 2:



Timeline 3:

The second investment step is made at time τ_2. The optimal investment time for this second (final in the case of $n > 2$) investment step can easily be derived. We introduce a lemma's to determine τ_2^*.

Lemma: If the second investment step is profitable, two cases can occur: $\tau_2^* = \gamma \; if \; \tau_1^* + \vartheta < \gamma$ or $\tau_2^* = \tau_1^* + \vartheta \; if \; \tau_1^* + \vartheta \geq \gamma$. Proof in appendix A.

The lemma shows that the second (final in the case of $n > 2$) investment step will be made at time γ or as soon as possible after γ if the policy is implemented during the time interval $[\tau_1^*, \tau_1^* + \vartheta]$.

Therefore, it remains to derive the optimal investment time of the first investment step, τ_1^*.

Appendix A

Proof of lemma

Part 1

In the following, we limit the analysis by proving that some decisions are not optimal. We proof that refraining from making the second investment step before the policy arrives, is better or at least equal compared to not refraining from making the second investment before the policy arrives.

We consider the investment choices of a firm, as of time $\tau_1^* + \vartheta$, and assume that γ has not yet occurred. The investment choices are: (i) make the second investment step during the interval $[\tau_1^* + \vartheta, \gamma[$, (ii) refrain from making the second investment step before the arrival of the policy. To prove that the second investment choice is better or at least equal compared to the first investment choice at all times, we consider and compare the discounted cash flows of both choices. The left side of the equation represents option (ii), and vice versa.

$$\int_{\tau_1^*+\vartheta}^{\gamma} \left[\left(P\left(1 - q_{B,1}\right) + P\delta q_{B,1}\right)e^{-rt}dt\right] \overset{?}{\gtreqless} \int_{\tau_1^*+\vartheta}^{\tau_2^*} \left[\left(P\left(1 - q_{B,1}\right) + P\delta q_{B,1}\right)e^{-rt}dt\right] + \int_{\tau_2^*}^{\gamma} \left[\left(P\left(1 - (q_{B,1} + q_{B,2})\right) + P\delta(q_{B,1} + q_{B,2})\right)e^{-rt}dt\right]$$

$$\Leftrightarrow \frac{\left(P\left(1 - q_{B,1}\right) + P\delta q_{B,1}\right)}{re^{(\tau_1^*+\vartheta)}} - \frac{\left(P\left(1 - q_{B,1}\right) + P\delta q_{B,1}\right)}{re^{(\gamma)}} \overset{?}{\gtreqless} \frac{\left(P\left(1 - q_{B,1}\right) + P\delta q_{B,1}\right)}{re^{(\tau_1^*+\vartheta)}} - \frac{\left(P\left(1 - q_{B,1}\right) + P\delta q_{B,1}\right)}{re^{(\tau_2^*)}} + \frac{\left(P\left(1 - (q_{B,1} + q_{B,2})\right) + P\delta(q_{B,1} + q_{B,2})\right)}{re^{(\tau_2^*)}} - \frac{\left(P\left(1 - (q_{B,1} + q_{B,2})\right) + P\delta(q_{B,1} + q_{B,2})\right)}{re^{(\gamma)}}$$

$$\Leftrightarrow \frac{\left(P\left(1 - q_{B,1}\right) + P\delta q_{B,1}\right)}{re^{(\tau_2^*)}} - \frac{\left(P\left(1 - q_{B,1}\right) + P\delta q_{B,1}\right)}{re^{(\gamma)}} \overset{?}{\gtreqless} \frac{\left(P\left(1 - (q_{B,1} + q_{B,2})\right) + P\delta(q_{B,1} + q_{B,2})\right)}{re^{(\tau_2^*)}} - \frac{\left(P\left(1 - (q_{B,1} + q_{B,2})\right) + P\delta(q_{B,1} + q_{B,2})\right)}{re^{(\gamma)}}$$

$$\Leftrightarrow \left(P\left(1 - q_{B,1}\right) + P\delta q_{B,1}\right) \geq \left(P\left(1 - (q_{B,1} + q_{B,2})\right) + P\delta(q_{B,1} + q_{B,2})\right)$$

Which holds, because ($\delta \in [0,1]$). This means that the second investment choice, which is refraining from making the second investment step before the policy arrives, is better or at least equal compared to the first investment option at all times.

Part 2

We proof that if the second investment step is profitable, it will be made at the arrival time of the policy. If the minimal withholding period ϑ has not yet expired, the second investment step will be made as soon as possible, namely at the time $\tau_1^* + \vartheta$.

We consider the discounted cash flows as of γ. Following the above, we assume the second investment step has not yet been made. The left side of the equation represents the investment choice to make the second investment at a point after the policy arrival, the right side represents the a coinciding policy arrival time and investment timing.

$$\int_{\gamma}^{\tau_2^*}\left[\frac{q_{B,1}}{\overline{q_B}}\left(P\left(1-q_{B,1}\right)+P\delta q_{B,1}\right)e^{-rt}dt\right]$$

$$+\int_{\tau_2^*}^{\infty}\left[\frac{(q_{B,1}+q_{B,2})}{\overline{q_B}}\left(P\left(1-(q_{B,1}+q_{B,2})\right)+P\delta(q_{B,1}+q_{B,2})\right)e^{-rt}dt\right]\overset{?}{\lesseqgtr}\int_{\gamma}^{\infty}\left[\frac{(q_{B,1}+q_{B,2})}{\overline{q_B}}\left(P\left(1-(q_{B,1}+q_{B,2})\right)+P\delta(q_{B,1}+q_{B,2})\right)e^{-rt}dt\right]$$

$$\Leftrightarrow \frac{q_{B,1}\left(P\left(1-q_{B,1}\right)+P\delta q_{B,1}\right)}{\overline{q_B}re^{\gamma}}-\frac{q_{B,1}\left(P\left(1-q_{B,1}\right)+P\delta q_{B,1}\right)}{\overline{q_B}re^{\tau_2^*}}+\frac{(q_{B,1}+q_{B,2})\left(P\left(1-(q_{B,1}+q_{B,2})\right)+P\delta(q_{B,1}+q_{B,2})\right)}{\overline{q_B}re^{\tau_2^*}}-\frac{(q_{B,1}+q_{B,2})\left(P\left(1-(q_{B,1}+q_{B,2})\right)+P\delta(q_{B,1}+q_{B,2})\right)}{\overline{q_B}re^{\infty}}\overset{?}{\lesseqgtr}\frac{(q_{B,1}+q_{B,2})\left(P\left(1-(q_{B,1}+q_{B,2})\right)+P\delta(q_{B,1}+q_{B,2})\right)}{\overline{q_B}re^{\gamma}}-\frac{(q_{B,1}+q_{B,2})\left(P\left(1-(q_{B,1}+q_{B,2})\right)+P\delta(q_{B,1}+q_{B,2})\right)}{\overline{q_B}re^{\infty}}$$

$$\Leftrightarrow \frac{q_{B,1}\left(P\left(1-q_{B,1}\right)+P\delta q_{B,1}\right)}{re^{\gamma}}-\frac{q_{B,1}\left(P\left(1-q_{B,1}\right)+P\delta q_{B,1}\right)}{re^{\tau_2^*}}+\frac{(q_{B,1}+q_{B,2})\left(P\left(1-(q_{B,1}+q_{B,2})\right)+P\delta(q_{B,1}+q_{B,2})\right)}{re^{\tau_2^*}}\overset{?}{\lesseqgtr}\frac{(q_{B,1}+q_{B,2})\left(P\left(1-(q_{B,1}+q_{B,2})\right)+P\delta(q_{B,1}+q_{B,2})\right)}{re^{\gamma}}$$

$$\Leftrightarrow \frac{q_{B,1}\left(P\left(1-q_{B,1}\right)+P\delta q_{B,1}\right)}{re^{\gamma}}-\frac{q_{B,1}\left(P\left(1-q_{B,1}\right)+P\delta q_{B,1}\right)}{re^{\tau_2^*}}\overset{?}{\lesseqgtr}\frac{(q_{B,1}+q_{B,2})\left(P\left(1-(q_{B,1}+q_{B,2})\right)+P\delta(q_{B,1}+q_{B,2})\right)}{re^{\gamma}}-\frac{(q_{B,1}+q_{B,2})\left(P\left(1-(q_{B,1}+q_{B,2})\right)+P\delta(q_{B,1}+q_{B,2})\right)}{re^{\tau_2^*}}$$

$$\Leftrightarrow q_{B,1}\left(P\left(1-q_{B,1}\right)+P\delta q_{B,1}\right)\overset{?}{\lesseqgtr}(q_{B,1}+q_{B,2})\left(P\left(1-(q_{B,1}+q_{B,2})\right)+P\delta(q_{B,1}+q_{B,2})\right)$$

$$\Leftrightarrow \left(P\left(1-q_{B,1}\right)+P\delta q_{B,1}\right)\overset{?}{\lesseqgtr}\left(1+\frac{q_{B,2}}{q_{B,1}}\right)\left(P\left(1-(q_{B,1}+q_{B,2})\right)+P\delta(q_{B,1}+q_{B,2})\right)$$

A firm will make its second investment step at the arrival time of the policy. If the minimal withholding period ϑ has not yet expired, the second investment step will be made as soon as possible, namely at the time $\tau_1^*+\vartheta$. If the equation does not hold, the second investment step will not be made at any future time.

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