SELF-CONTROL AGAINST HALF-INTUITIVE REACTIONS

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ABSTRACT

Title of Dissertation	Self-Control Against Half-Intuitive Reactions
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People often make everyday decisions based on their intuition. A large number of experiments in Neuroeconomics and Behavioral Economics draw this conclusion without providing explanations on the reaction-generating processes. These intuitive reactions are efficient and appropriate in many situations. However, when the issue at stake concerns immediate rewards; intuitive reactions usually lead to suboptimal results. In fact, these continued reaction patterns may breed bad habits and act as endogenous constraints to one's making an optimal choice. They can eventually cause major undesirable consequences.

This paper offers a model which explains intuitive reaction processes and bridges the literature on Self-Control and Bounded Rationality. It aims to tackle the abovementioned impulsive reactions right away at the time the reactions take place, in an extremely impulsive setting.

The model explains the mental supply formation steps: starting from being aware of the event in question, searching the reactions, to executing the reactions which come from either a rational or a bounded rational system. These four elements: awareness, predetermined reactions, self-control, and rational/bounded rational, form a mental supply state of an individual. While the latter two elements link the paper to the Self-Control and Bounded Rationality literature, the former two are the main highlights of this paper. In the extremely impulsive setting, awareness and predetermined reactions are scarce; hence, they underpin the mental supply sufficiency and consequently determine the reaction result.

After the formation phase, the eventual reactions come from compatibilities between the controllable mental supply and the given mental demand. Finally, the conditions for these compatibilities are explored to find the optimal reaction strategies of which validity rests on the willingness and determination of people to control their mental supply. The paper suggests that, by bringing conscience and self-control into people's intuitive-reaction sphere, people's endogenous constraints can be removed and their utilities enhanced.

ACKNOWLEDGEMENTS

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Thanks to Archarn Amornrat Apinunmahakul who helps draw it up from scratch, puts up with many alien imagination, and attempts to keep the model and myself back on track!

Thanks to Archarn Suchittra Chamnivickorn, my greatest mentor, for your forever support, patience during hours of discussions, and useful suggestions. You add meanings and liveliness to the model and me!

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Pakathorn Na Pattalung

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CHAPTER 1

THE ISSUE

People like to enjoy immediate impulsive rewards and delay costs. The sophisticated ones are aware of this time-inconsistency trap and try to control themselves. However, in certain situations when impulses seem irrelevant and insignificant, people react following their intuitive desires and usually end up with suboptimal results.

This study bridges the literature on Self-Control and Bounded Rationality and offers a model which explains the intuitive reaction processes. It proposes an optimal mental state and the reaction strategies to tackle the impulsive reactions which lead to negative results. The model shows that these reactions can be fine-tuned by a simple forethought with a few more deep breaths, or a slight increase of predetermination and awareness.

In this chapter, the issue of interest is defined. However, the issue cannot be seen solely through the rational lens. Neither could it be explained clearly from the self-control nor bounded rationality perspectives. As a result, in chapter two, we propose a theory, combining features from the three views. The decision-maker's mental state and its reaction speed determine the eventual reactions. From there, the study continues with a set of reaction strategies and the relevant proof to ensure that the proposition is indeed utility enhancing. However, it rests on an assumption of full information.

Chapter three includes the relevant empirical tests to justify the related assumptions and investigate the key determinants of the result. It also contains some applications to the real world.

1.1 Observations of the Problem

…"What have I done! I shouldn't have reacted like that!"

…"I can't imagine that such a simple thing could cost me this much!"

It is common to observe day-to-day suboptimal choices from intuitive reactions. But, with time, the eventual effect of these seemingly minor issues can be immense. Causes of various issues such as drug addiction, unplanned crime, accidents, various health problems, credit card debt, and low GPA score are complicated but they do share something in common. Something is wrong somewhere with the intuitive reactions.

Consider for example: A student would like to pass an exam. He decides to study. Walking to a library, he meets a friend who invites him to a party. The student turns down the party proposal. In the library, while he tries to understand an important part in a book, a person walks past by his reading table and hums a melody from a song. The student acknowledges the presence of the passerby, recognizes the melody, recalls some memories, and loses his concentration on the book. Physically, he is still sitting; his eyes are looking at the book. Mentally, he is half-seeing the book and half-wondering about something else. He fails the exam.

The situation involves an individual who tries to do certain activities according to his plan. Look at it in three stages: a long-term or planning stage, a short-term or self-control stage, and an extremely impulsive or half-intuitive stage.

The student plans to study in the planning stage. Then, he follows the plan and manages to go to the library instead of the party. This is the short-term stage which involves self-control actions to turn down tempting choices. He might imagine what would happen if he fails and uses that fear as an internal commitment mechanism to suppress the desire to party. The short-term stage entails one important character of human nature known as time inconsistency which involves hesitations to follow the predefined plan due to short-term impulses. In these first two stages, the student is rational. He has full conscience of the relevant costs, benefits, and choices when he makes decisions.

The third stage starts when he hears the melody, recalls certain memories, and loses the concentration on the book. Here, impulses take the form of minor distractions and the student reacts partly following his perception and intuition. His mental state is not fully rational; it is bounded rational. Besides, he also does not take these impulses as seriously as he does with the party invitation. Thus, self-control is not in sight in this extremely impulsive or half-intuitive stage. The situations which are characterized by the elements of this stage are in the extremely impulsive setting. They are the situations of focus here.

These three stages provide different ways to look at decision-making processes. While the separation is fictitious, it helps to highlight the main ideas:

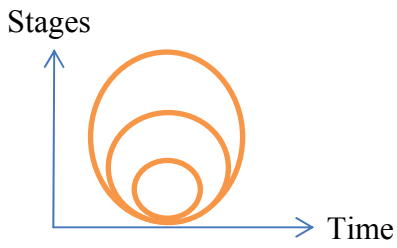

Figure 1.1 The Time-Links between the Three Stages

Long-term stage (rational) is shown in the outermost ring e.g. Becker's and Heckman's human capital formation models. Short-term stage (rational but time-inconsistent) is defined in the middle ring e.g. self-control models with the competition between willpower and desire, according to Hoch and Loewenstein (1991). The Extremely impulsive stage (bounded rational or half-intuitive) is displayed in the innermost ring.

1.2 A Long-Term or Planning Stage: Rational Choice

Decisions in this stage correspond to the rational choice behavior. They are also known as "system 2" as per Kahneman (2011). According to Mas-Colell et al. (1995), a decision-maker has a preference which has two important properties: completeness and transitivity. Hence, he has a clear and unaltered preference between

the possible choices. This yields a well-defined utility function and makes it possible to calculate the best choice with regard to the constraints.

As per Kahneman (2011) and Camerer (2005), several studies and experiments show that the decision-making processes are more complicated. The rational choice approach is slow, effortful, and subject to several biases. The most relevant issues for this study are self-control and intuitive reaction. They are briefly discussed in the next sections.

In any case, the rational choice approach can be applicable in many situations. In fact, it is regarded as a base-line, standard way of economics analysis. From the example, the decisions to study and to turns down the invitation certainly involve rational choices. The forthcoming model in the theory chapter includes the rational choice option. The decision maker will have a final say whether he will base his reaction on this option. It is designed to correspond to its slow and effortful characters so it is labeled here as a system in the long-term or planning stage.

1.3 A Short-Term or Self-Control Stage: Time-Inconsistency Bias

Decisions in this stage also correspond to the rational choice behavior. However, the focus is on action executions part. In this stage, a decision-maker confronts with sudden changes in preferences and hesitates to follow his rational plan.

According to Strotz (1956), these time-inconsistent preferences come from a present-biased nature of human. Camerer (2005); and Hoch and Loewenstein (1991) confirm that such preferences are observed since the study of Adam Smith (1790) and Alfred Marshall (1920). Kahneman and Tversky (1979) add that it may also come from a sudden shift in the psychological reference point.

The concept of controlling one's self against one's own desire is helpful in explaining the situation at hand. However, rational desires are different from impulsive reactions. No one plans to have an unplanned accident as it is certainly utility decreasing. As these impulsive reactions are only partly controllable and partly intuitive, a model is developed in another specific stage.

1.4 An Extremely Impulsive Term or Half-Intuitive Stage

The situation of this study is unique. As it does not fit in the first two stages, a specific stage is defined to capture its characteristics.

1.1 Observations of the Problem

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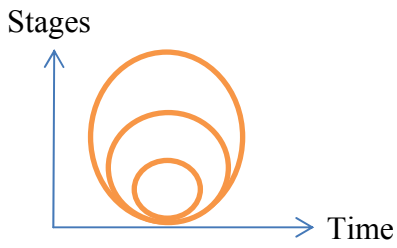

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The previous two pages illustrate the concept of impulsive reactions. Hopefully, they manage to invoke the reader's impulsive reactions that pages 2 and 3 are erroneously repeated.

Kahneman (2003) suggests that the natural architecture of human cognition involves the coordination of the two fictitious systems, a slow rational system and a fast intuition one. The rational system is slow, serial, controlled, effortful, rule-governed, and neutral. The intuition system is fast, parallel, automatic, effortless, associative, and emotional. When a decision-maker faces a situation, each system has different accessibility to different features of the situation, and the eventual behavior depends on the coordination of the two systems.

Camerer, Loewenstein, and Prelec (2005); and Brocas and Carrillo (2008) support this two-system framework with recent neuroscience evidences e.g. brain imaging, transcranial magnetic stimulation.

Impulsive reactions are the focus of this study. They occur under the extremely impulsive setting in this half-intuitive stage. This extremely impulsive setting will be further defined in Chapter two.

1.5 The Research Question

The aim is to identify ways to respond better in the extremely impulsive settings. The pioneering attempt to find the optimal behavioral rules or reaction strategies comes from a study by Bénabou and Tirole (2004). According to them, individuals control short-term impulses to respect their self-reputation. They are strict in controlling their behavior when they remember past lapses and wish to avoid damaging their reputation. Different levels of self-reputation and the ability to recall lapses strengthen their willingness to resist impulses.

Bénabou and Tirole broadly classify individuals into two groups according to their strength of will: the strong-willed who generally tries to persevere and the weak-willed who gives up more easily. To study different behavioral responses of each group, they subsequently define four behavioral rules. Impulsive behavior applies when each group acts following his/her impulses. Flexible rule believer gives up only when the cost is too high. With bright-line behavior, both groups always persevere.

And with compulsive behavior, the strong-willed always perseveres and the weak-willed always gives up. In some cases, individuals decide to act myopically and adopt impulsive behaviors; while in other cases, individuals adopt excessively rigid rules which in turn lower their welfare. In fact, different situations call for different behavioral rules. One should not be too harsh to oneself when the cost of self-control is far too high. Neither should one be over impulsive to the level that damages self-reputation. Hence, Bénabou and Tirole conclude by suggesting optimal behavioral rules in each situation.

This study follows the similar research path with the objective to find optimal behavioral rules allowing individuals to control their own undesirable impulses. While Bénabou and Tirole focus on the self-control stage, this study investigates the issue in the extremely impulsive stage which perception and intuition strongly influencing individuals' reactions. This places us one step away from fully rational self-control models and one step closer to the bounded rationality literature.

Using the previous example to define the issue at stake: when the student loses his concentration, what is the problem? If one slowly reconsiders the situation: the student would like to pass the exam so he plans to study, comes to the library, loses his concentration, and finally fails the exam. This series of actions leads to the eventual result. To come to the library and study certainly do not guarantee that he will learn necessary materials for the exam. It is the effective learning by means of mental concentration and thinking processes that counts. If someone asks him whether he knows this fact, a reply will be positive. No one expecting to pass the exam plans to lose his concentration to study. So, the problem comes from distractions which seem unimportant at that time, in the extremely impulsive setting. The distractions match well with his intuitive reactions, so his mind accommodates them naturally and shifts away from concentrating on the book. In this line of reasoning, the key determinants are the student’s mental state and its response speed. If he is very determined and his mind concentrates on studying, it would be more difficult for him to be distracted. So, the objective is to identify a set of behavior or mindset that reinforces concentration and suppresses distractions.

1.6 Value-Added of This Dissertation

The impulsive reactions usually lead to suboptimal results. In fact, these reaction patterns may breed bad habits and act as endogenous constraints to one's making an optimal choice. They can eventually cause major undesirable consequences. Because of this, handling these reactions properly removes constraints to the objective function, broadens feasible choices, and thus enhances utility.

To do so, this study mainly focuses on the two mental state elements: awareness and predetermined reactions. As briefly introduced, mental supply is formed by the four steps: awareness, predetermined reactions, self-control, and rational/bounded rational. All these steps will be explained in detail in the model part. Each step yields a binary result: 0 or 1. So, the sixteen, 2^4, possible mental states can be broadly classified into four different groups as:

1) Self-control: Mental states are represented in the form *{a1, d1,* ***c0 or c1****, r0 or r1}*. There are four mental states, 1·1·2·2, in this group. A vast set of literature on Self-control deals with the presence and the absence of the third element, *c*.

2) Rational: The mental state *{a1, d1, c1,* ***r1****}* represents all rational choice decisions, from optimization to game theory.

3) Bounded rational: The four states *{a1, d0 or d1, c0 or c1,* ***r0****}* account for intuitive reactions according to Kahneman (2012). Note that the first element here is *a1*; thus, awareness is active.

4) Unaware and impromptu (non-predetermined): These eight unaware states *{****a0****, d0 or d1, c0 or c1, r0 or r1}* and four impromptu states *{a1,* ***d0****, c0 or c1, r0 or r1}* are the main focus of this study.

From the first three groups, the state *{a1, d1, c1, r1}* and the two states *{a1, d1, c0 or c1, r0}* are already included in the first group. The two states *{a1, d0, c0 or c1, r1}* are also counted in the fourth group; hence, overall the first three groups account for four mental states. The fourth group accounts for twelve less-effective states. The study's eventual aim is to substitute these inferior twelve states with the former superior four. Its value-added is then the increased utility obtained from the improved mental states.

One possible application is on education and labor supply efficiency. From a micro view, this knowledge can help students or workers manage their concentration and suppress distractions. From a macro view, this may lead to some changes in the ways to organize the class or working conditions. Perhaps before each class, a teacher should present objectives and important points of the session. Students may meditate to prepare their minds. After each session, the teacher calls for full attention, concludes and reviews important points to help relate important concepts with those from previous sessions. Concentration of students should also be considered to determine various aspects of the learning session to make sure that it comes in an absorbable manner. Similarly, workers work more efficiently when they concentrate. The working conditions should be arranged to accommodate that. Positive changes will increase the overall labor supply efficiency, competitiveness and happiness.

Chapter three includes some statistics and hints other possible applications on accident prevention, crime reduction, and health improvement.

CHAPTER 2

THEORY OF SELF-CONTROL AGAINST HALF-INTUITIVE REACTIONS

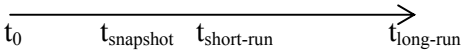
Before turning to the model, few concepts are introduced:

Definition 1 (Act ivities): Let a mental-supply bundle H consists of a sequence of activity inputs $h^+_1, h^+_2, \ldots, h^+_n$ which are necessary and efficient to produce a mental output H'. A bundle I is defined similarly. Hence, $H = \{\boldsymbol{h}^+\}$ and $I = \{\boldsymbol{i}^+\}$. $\boldsymbol{h}^-$ and $\boldsymbol{i}^-$ consist of activities which are not the members of $\boldsymbol{h}^+$ and $\boldsymbol{i}^+$ respectively. Loosely, the terms activity, sub-activity, and event mean the same thing, the mental-supply container. To simplify further, the superscripts are removed, the inputs $\boldsymbol{h}^+$ is referred only when $\boldsymbol{h}^-$ is relevant.

From the example: *H′ = {studied materials for the exam}*, *H = {turn to the related chapters, look at the text, read the first sentence, understand the first sentence,…}*, *I′ = {daydreaming}*, and *I = {recognize the melodies, recall some memories, create a story,…}*.

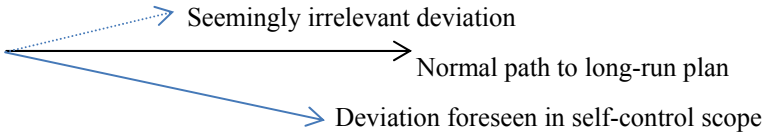
Definition 2 (Extremely Im pulsive Setting or EIS): An individual encounters an event *i.* The event is considered to be in the extremely impulsive setting if it meets the following three conditions at the time the event occurs.

Condition EIS1 (Snapshot): The relevant time is very short, almost instantaneous. The individual defines this subjectively.

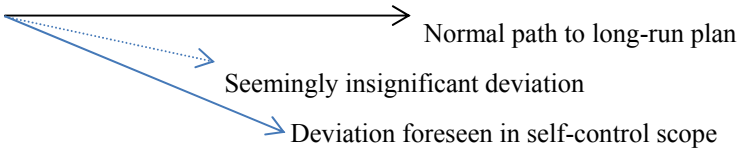


Two pages are intentionally left blank to illustrate the swiftness according to Condition EIS1.

Condition EIS2 (Seemingly Irrelevant): While the event deviates ones from the long-run plan, the individual feels that the event *i* is irrelevant to his self-control scope.



Condition EIS3 (Seemingly Insignificant): While the event deviates ones from the long-run plan, the individual feels that the event *i* is insignificant to his self-control scope.



To clarify the above conditions: At the time the student briefly loses concentration, everything seems automatic and he is not even aware of it. He might have a slight flash of reflection but then his half-conscience considers that the distraction is insignificant and irrelevant. In this situation, the student encounters the event in the extremely impulsive setting as the three conditions are satisfied.

Definition 3 (Pareto-Superior Behavioral Rules or **Optimal Reaction Strategy):** A reaction R is (ex post) Pareto-superior to a reaction R´ if, when confronted with a series of events in the extremely impulsive settings, the individual is better-off if the reaction R is played rather than the reaction R´. This criterion will be used to find the optimal reaction strategy.

2.1 The Model

Organization of the model:

2.1.1 Mental State Formation: related components and their logical sequences

2.1.2 Reaction Determination: matching of mental state supply and demand

To study self-control against half-intuitive reactions in the extremely impulsive setting, the issue is examined in two steps: mental state formation and reaction determination. Then, the model will be used to shed light on the optimal reaction strategy.

2.1.1 Mental State Formation

The process starts from an individual who reacts to the activity *h* and suddenly faces with the event *i*. The event *i* is subsequently followed by an event *j* which is defined similarly. The event *i* is in the EIS as defined in Definition 2.

Let imagine the possible situations. From Definition 1, while doing the activity *h*, a member of the bundle *H*; the possible following activities are either an activity h_1, which is another member of the bundle *H*, or an activity *i*, a member of the bundle *I*. The first possibility is less relevant, because reacting to the activity h_1 without being aware of the activity *i* is by definition similar to saying that the activity h_1 is similar to the activity *h* and we are back to where we start. So, in this case, the individual simply fill up the bundle *H* and there is no problem.

Recall that the activity *i* is defined as a member of the bundle *I* which is a different mental supply container from to the bundle *H*. Moreover, in reality, a sequence with frequent-alternating activities such as $\{h_1, i_1, h_2, i_2, i_3, h_3,...\}$ is more realistic than the less frequent one such as $\{h_1, h_2, h_3,..., h_n, i_1, i_2, i_3,..., i_n\}$. In addition, even when one encounters with the latter sequence, the possible points of intervention are still at the *h*-*i* connections e.g. $\{..., h_n, i_1,...\}$ anyway.

Take these two examples to illustrate the above: while drinking a glass of cocktail, H_1 = *{..., smell, sip, feel the taste, swallow, ...}* and I_1 = *{..., recognize the possibility to stop, think about the pros and cons, stop drinking,...}*; or while sitting in

a bar, H_2 = *{..., chat with friends, hear what friends say, process to understand the meaning,...}* and I_2 = *{..., call the waiter, order a glass of cocktail, smile, ...}*. In any case, the mental formation process must start from the point where one is doing *h* and encounters the event *i* in the EIS. This is where the model starts:

Assumption 1 (Mental Supply Formation Steps): An individual's mental supply for the event *i* in the EIS, according to Definition 1 and 2, is endogenously determined by the following steps:

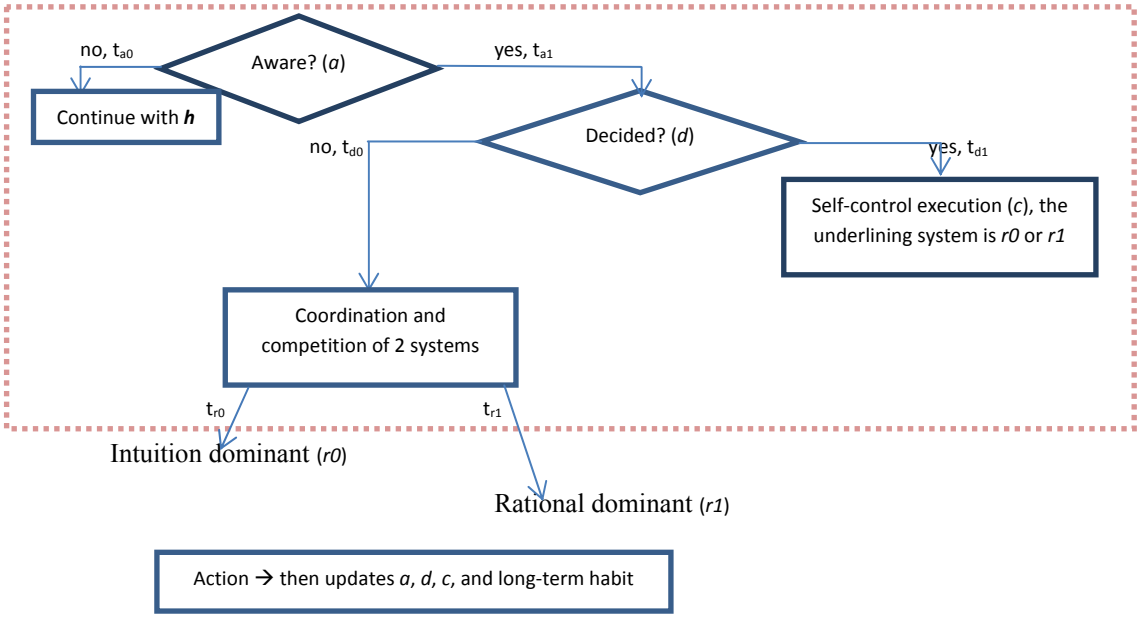


Figure 2.1 Mental Supply Formation Steps

Facing with the event *i*, if the individual is not aware of it, then by definition he encounters a sequence *{h, h_1,...}* and continues with the activity h_1. On the other hand, if he is aware of the alternative container *i*, the formation steps start.

In reality, the event *i* is rarely unprecedented. Its reactions are, hence, usually predetermined. The individual invokes his self-control to formulate the reactions accordingly. Often, however, the individual may choose to define it differently as an excuse to avoid executing self-control.

q

The two earlier pages illustrate the event *i* defined as "encountering two (almost) blank pages" which happened earlier on page 13. However, as page 18 contains a letter q, some people might claim that this event differs from the one on page 13 as an excuse to avoid executing self-control. From the continuing example of section 1.1, what happens if the student is invited by another friend after he turns down the invitation of the first friend? Even if it is the same party, perhaps he might react differently and end up accepting the invitation. This is an important feature of the predetermined reactions step. It captures time-inconsistency and self-deception issues, in the EIS.

The above two steps are the highlights of this study. They are labelled awareness and predetermined reactions steps. The remaining two steps: self-control and rational, connect this model with the existing literature on Self-control, Rational Choice, and Bounded-rationality. To continue with Figure 2.1, here are the related components and their sequence:

1) There are four steps or processes, a-process, d-process, c-process, and r-process. Each process takes the event *i* as its input. The event *i* then passes through some checks. The outputs from the four processes form four elements representing a specific mental state.

Assumption 2 (Supply Formation Threshold): There exists an information set $\ddot{I} = \{i_a, i_d, i_c, i_r\}$ representing the minimum threshold of each element for process *a*, *d*, *c* and *r*. This set is subjectively predetermined in the self-control stage. The member of the set $\ddot{I}$ is empty when that process is not predetermined. Each element is defined in the following part.

Definition 4 (Supply Formation Process): The process takes the event *i* as its input and yields element p_i as its output. The *p-process*, *p(.)*, generates two possible outputs: *p0* or *p1*.

$$p_i \begin{cases} = p0 \text{ if } i_p \notin \ddot{I}. \\ = p1 \text{ if } i_p \in \ddot{I}. \end{cases}$$

This definition is then used to generate the following processes and outputs:

2) The first process is a-process or awareness. The individual senses via his self-monitoring and becomes aware of the event *i* when the awareness of such activity is sufficiently clear to his conscience:

$i_a \notin \ddot{I}$ *or* $i_a = \{\ \} \rightarrow a_i = a0$ *or i is not aware*

$i_a \in \ddot{I} \rightarrow a_i = a1$ *or i is aware*

With the element *a0*, the event *i* is not aware, so the individual continues with the activity *h*.

With the element *a1*, the next processes continue. (see the right-arm of the first node of Figure 2.1)

3) D-process or decided represents a rapid check whether the reaction for the event *i* is predetermined. An element *d0* means there is no predetermined/ predecided reaction so the reaction will have to be determined by the *r-process*, while an element *d1* means the individual has a predetermined reaction which might come from his habit, behavior, or preplanned self-control. In this process, the event *i* will also be judged whether it is a key event. That is $\{i\} \in \{\boldsymbol{i}^{+}\}$, *or* $\{i\} \in \{\tilde{\boldsymbol{\imath}}\}$. So the d-process assigns the experience and importance values.

In the same way, it can be written as:

$i_d \notin \ddot{I}$ *or* $i_d = \{\ \} \rightarrow d_i = d0$

$i_d \in \ddot{I} \rightarrow d_i = d1$

4) C-process or self-control execution represents a self-control execution reaction for the event *i*. An element *c0* means the self-control execution is not successful while an element *c1* means it is successful:

$i_c \notin \ddot{I}$ *or* $i_c = \{\ \} \rightarrow c_i = c0$

$i_c \in \ddot{I} \rightarrow c_i = c1$

5) R-process or rationale represents the underlining decision system. An element *r0* means the reaction comes from the intuition system according to Kahneman (2003). An element *r1* represents the one from the rational system. Hence:

$$i_r \notin \ddot{I} \text{ or } i_r = \{\ \} \rightarrow r_i = r0$$
$$i_r \in \ddot{I} \rightarrow r_i = r1$$

6) To represent the four elements characterizing the mental state of the individual in the extremely impulsive setting, the four binary variables *a*, *d*, *c*, *r* are used and written together as *{a,d,c,r}*. In the situations where the value of certain member is irrelevant, only the relevant element(s) is(are) mentioned. For example, the state *{a0}* refers to the first situation in the above table, the state *{a1}* refers to the other six situations, the state *{a1,d0}* refers to the states *{a1,d0,r0}* and *{a1,d0,r1}*.

7) The possible mental states include:

Table 2.1 Mental States

a	***d***	***c***	***r***	***Definition***
0	0 or 1	0 or 1	0 or 1	With the state *{a0}*, either the activity *h* is uninterrupted or the total processing time is too long. Thus, the value of the remaining variables is not relevant. This represents the unaware reaction.
1	0	0 or 1	0	The event *i* is aware but there is no predetermined reaction. So, the value of c-process is not relevant. With this state *{a1,d0,r0}*, the individual reacts following his intuition. It is a first-time *intuition* reaction to the event *i*.
1	0	0 or 1	1	The event *i* is aware but there is no predetermined reaction. So, the value of *c-process* is not relevant. With this state *{a1,d0,r1}*, the individual reacts following his rationale. It is a first-time rational reaction.
1	1	0	0	The event *i* is aware. There is a predetermined reaction but it is not successfully controlled, so it is not delivered as intended. The state *{d1,c0,r0}* implies that the reaction is influenced by habit, behavior and intuition. It is called a habit-intuition reaction.

Table 2.1 (Continued)

a	*d*	*c*	*r*	*Definition*
1	1	0	1	The event *i* is aware and there is a predetermined reaction but it is not successfully controlled. As a result, the reaction is not delivered as intended. The state *{d1,c0,r1}* implies that the reaction is influenced by habit, behavior and rationale. Hence, it is called a habit-rational reaction.
1	1	1	0	The event *i* is aware and there is a predetermined reaction which is successfully controlled. This intuitive reaction is also delivered as intended. It is a planned-intuition reaction.
1	1	1	1	The event *i* is aware and there is a predetermined reaction and it is successfully controlled. This rational reaction is also delivered as intended. It is a planned-rational reaction.

8) While the state *{a0}* and the four states *{a1,d1}* represent the reactions to the event, the two states *{a1,d0}* either lead to the unaware reaction *{a0}* or respond directly as the states *{a1,d0,r0}* or *{a1,d0,r1}* depending on the processing time. This is noted in the dotted frame of Figure 2.1. If the time for r-process takes too long, the state *{a0}* will be the reaction. If the element *{r}* is rapidly determined, one of the two states *{a1,d0}* will represent the reaction.

9) The link between self-control models and this model can be found in the four states *{d1}*. In the short-term stage, the individual decides on the optimal level of self-control; however, in the extremely impulsive setting, he does not have full control over the execution of such decision. The states *{d1,c1}* represent the cases where the self-control decision successfully influences impulsive reactions. The states *{d1,c0}* represent the cases where habit and behavior are more powerful than self-control decision.

10) Time is another key determinant in the mental formation phase. The total time to react includes the time to determine each element of the mental state. The reaction comes too late if it is slower than the speed of change of the event *i* to

the event *j*. On the contrary, the reaction is timely when it takes place before the event *i* changes to the event *j*.

This is represented by:

$T \equiv t_a+t_d+t_c+t_r$ for all elements of mental state for the event *i*.

$T > s_{ij}$ → reaction is not in time, the state $\{a0\}$ represents the reaction.

$T \leq s_{ij}$ → reaction is in time. The reaction is $\{a,d,c,r\}_i$.

The result of the formation step is the mental state supply to the event *i* or $S_i = \{a,d,c,r\}_i$. Together with the required mental state demand for the event *i*, D_i, they determine the eventual reaction.

2.1.2 Reaction Determination

The required mental state for the event *i*, D_i, is exogenous to the model. The usual rules apply, so:

$S_i = D_i$ → mental state supplied matches with the one demanded

$S_i > D_i$ → mental state is over-supplied by S_i-D_i

$S_i < D_i$ → mental state is under-supplied by D_i-S_i

In the first two cases, as highlighted in Table 2.2, the intended reaction is carried out. In the last case, it is not.

Different types of mental state may be supplied and demanded in order to produce different outputs. The model can be extended by including the production function which turns different mental state inputs to different outputs. As the focus here is on the optimal reaction strategy, the matching results are directly presented:

Definition 5 (Mental Supply Effects):

Variable *A* is defined to capture the effect *a1-a0* from the awareness element on the mental state. It also captures the duration of time t_{a1}.

Variable *D* captures the effect *d1-d0* from the habit element and the duration t_{d1}.

Variable *C* captures the effect *c1-c0* from the self-control element and the duration t_{c1}.

Variable *R* captures the effect *r1-r0* from the rational element and the duration t_{r1}.

Probability ρ represents the chance that an element *{e}* of row S_i is not equal to an element *{e}* of column D_i.

The differences between the mental supply and demand, row S_i – column D_i, are:

Table 2.2 Matching Results

$S_i - D_i$	*{0,d,c,r}*	*{1,0, c,0}*	*{1,0, c,1}*	*{1,1,0,0}*	*{1,1,0,1}*	*{1,1,1,0}*	*{1,1,1,1}*
{0,d,c,r}	0	-A,-pC	-A,-pC,-R	-A,-D	-A,-D,-R	-A,-D,-C	-A,-D,-C,-R
{1,0, c,0}	A,pC	0	-R	-D,pC	-D,pC,-R	-D,-pC	-D,-pC,-R,
{1,0, c,1}	A,pC,R	R	0	-D,pC,R	-D,pC	-D,-pC,R	-D,-pC
{1,1,0,0}	A,D	D,-pC	D,-pC,-R	0	-R	-C	-C,-R
{1,1,0,1}	A,D,R	D,-pC,R	D,-pC	R	0	-C,R	-C
{1,1,1,0}	A,D,C	D,pC	D,pC,-R	C	C,-R	0	-R
{1,1,1,1}	A,D,C,R	D,pC,R	D,pC	C,R	C	R	0

Recall from Figure 2.1 that mental supply for the event *i* exists in sixteen different forms and processing time. These are captured within the variables S_i and *T* and summarized in Table 2.2 along with the mental demand, D_i. Eight unaware states *{a0}* and four non-predetermined ones *{a1,d0}* are shown in the first three groups. As noted earlier, these twelve forms are the usual mental states in the EIS and they highlight the contribution of this study. The four states *{a1,d1}* represent Self-control issue. Bounded rational takes shape in four states *{a1,r0}* and Rational is captured by the last form *{a1,d1,c1,r1}*.

Table 2.2 shows oversupplies in positive and undersupplies in negative with the missing element(s). Lower-left corners highlight those states which awareness and

predetermined reactions are nonnegative. Clearly, the only non-negative definite state is *{a1,d1,c1,r1}*.

While handling mental supply sufficiency in the EIS depends also on its management in Self-control and Bounded Rational/Rational stages according to their links in Figure 1.1, they are less focused for the purpose here but discussed in depth elsewhere. If one can ensure the non-negativities of self-control and rational elements, mental supply sufficiency only rests on the management of awareness and predetermined reactions.

Hence, the aim is to remove those non-highlighted upper-right-corner states and replace them with those highlighted ones.

The following two necessary reaction conditions are derived from Figure 2.1 and Table 2.2:

Condition R1 ***(In Time)*****:** $T \leq s_{ij}$

Condition R2 ***(Matching*** or ***Sufficient Mental Supply)*****:** $S_i \geq D_i$

That is, the reaction has to be in time and the mental state has to match with the required demand level. The term matching or sufficient mental supply represents the quality and quantity compatibilities between the mental state supply and demand. Unfortunately, observations show that these conditions are much easier to be satisfied in the paper than in reality. Next, the existing framework will be used to explore the flexibilities of the above conditions and find the solution.

2.2 The Optimal Reaction Strategy

At this point, let summarize and discuss all the relevant components of the model.

Storyline: The individual is reacting to the activity *h* and encounters the event *i.* The event *i* is in the *extremely impulsive setting* as it meets the three **EIS conditions** defined in Definition 2: EIS1 (Snapshot), EIS2 (Seemingly Irrelevant), and EIS3 (Seemingly Insignificant). The event *i* is followed by the event *j* which is defined similarly.

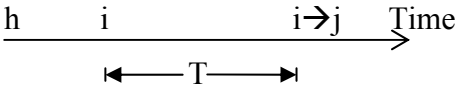


Figure 2.2 Storyline

Figure 2.2 illustrates the sequencing of the story. The model posits that the individual has the mental state supply, S_i, and the event *i* calls for the mental state demand D_i. The supply S_i is determined by the mental state formation processes while the demand D_i is exogenous to the model.

The variable T represents the total time to form the supply S_i and react to the demand D_i. The speed of change from the event *i* to the event *j* is represented by the variable s_{ij}. The individual reacts to the event *i* when the supply is determined in time. This is shown in Condition R1, $T \leq s_{ij}$.

During the mental state formation processes, the event *i* is checked against the predetermined set $\ddot{I}$ to generate each element of the supply $S_{i} = \{a,d,c,r\}_{i.}$ The matching of the states S_i and D_i determines the reaction to the event *i*. The individual reaction is carried out when he has sufficient mental supply. This is captured in Condition R2, $S_i \geq D_i$.

Note the two opposing forces of the model: Condition EIS1 implies the duration $T > s_{ij}$ as the usual intuitive reaction; while Conditions EIS2 and EIS3 suggest the set $\ddot{I} = \{\ \}$ as the habitual information set. To align the individual's reaction with his objective, the two counterintuitive conditions are suggested: $T \leq s_{ij}$

and $S_i \geq D_i$ or, equivalently, $\ddot{I} = \{i_a, i_d, i_c, i_r\}$. Referring to Figure 1.1, basically our aim is to expand the self-control scope and minimize the EIS area.

Given the storyline and the components of the model, let analyze the possible reactions of the individual. In a very fine activity-time scale, the individual may; react to the activity *h*, react to the activity *i*, or react to neither the activity *h* nor the activity *i*. However, in this tense situation, many variables are unknown and the reaction is not guaranteed to be done in time. That is, the duration of time *T* might be longer than the point which the activity *i* turns to the activity *j*. In addition, this happens under the bounded rationality sphere where the two decision systems, rational and intuition, compete and complement each other. All these facts support random results. So, sometimes the individual reacts to the activity *h*, sometimes to the activity *i*, and other times he simply gets confused.

To demystify this situation, the related factors are analyzed. First, more information on the two activities is needed. Chances are: both are the key activities, one of these two is the key activity, and none is the key activity. That is, $h \in \boldsymbol{h}^+$ or $h \notin \boldsymbol{h}^+$ and $i \in \boldsymbol{i}^+$ or $i \notin \boldsymbol{i}^+$.

In the same line, looking at the mental supply and demand for the activities *h* and *i*, it can be that the supply is sufficient for both, for one, or for none. So, $S_h \geq D_h$ or $S_h < D_h$ and $S_i \geq D_i$ or $S_i < D_i$.

To complete the permutation, it is also necessary to compare the utility of the output H' and the one of the output I'. As the two values $U(H')$ and $U(I')$ are determined from the self-control stage, at this point, the individual has a clear preference. It is either $U(H') > U(I')$ or $U(H') < U(I')$. All he has to do is to form the mental supply to match with the mental demand.

Before proposing reaction strategies, the following assumption is needed:

Assumption 3 (Full Information): At the time of reacting to the activity h and encountering with the activity i, the individual has full information and full conscience of these three issues:

1) Right Information on Matching Variables: The full information on S_h, D_h, S_i, D_i, H, I, $U(H')$, and $U(I')$.

2) Right Mind-Set: The individual is fully conscious of the situation, alert, and prepared to react. He devotes his mental supply to select the activity and reacts to it. This ensures the matching of the mental supply and the demand according to Reaction Condition R2.

3) Right Reaction and Right Time: From Reaction Condition R1, this assumption says that the individual plans and reacts following the reaction strategies in the forthcoming proposition. By doing that, the reaction time is also reduced to the minimum and Condition R1 is met, so $T_i < s_{ij}$.

In short, Assumption 3 requires that the information set takes the form $\ddot{I} = \{i_a,i_d,i_c,i_r\}$ which yields the mental supply $S_i = \{a1,d1,c1,r1\}_i$ and the minimum possible reaction time T_i.

Here, the assumption is analysed and justified that it is plausible. Note that its validity is needed only for the concerned snapshot period of time.

First, let check Assumption 3(1) element by element: The variable S_h stands for the mental supply of the activity h, $\{a,d,c,r\}_h$. From the storyline, the supply S_h represents the concentration on the subject being studied. It includes awareness, determination, controlled effort and mental processes to formulate the required knowledge. To react optimally as per the forthcoming proposition, the individual must have the conscience of his current mental supply for the activity h. In the real world, one usually observes that the awareness of the supply S_h is in place for many important activities, e.g. job interview, a test-drive session. Hence, it can be argued that the assumption is realistic when the activity is deemed important.

The demand D_h captures the required mental supply to react to the activity h. It is activity-specific and exogenous to the model (refer to Table 2.2 for the matching results). This assumption says that the individual has full knowledge of the demand D_h. In fact, the knowledge required is merely the relative value of the supply S_h and

the demand D_h. That is, while reading a chapter in a book, the individual knows how much he needs to concentrate and whether he has enough concentration to do it.

The supply S_i and the demand D_i could be interpreted similarly. Practically, the individual determines them from past experiences in combination with his forecast for the similar activities.

The mental supply bundle H consists of sub-activities $\boldsymbol{h}^+$, e.g. to understand a chapter in a book, one has to open the correct page, look at the words, retrieve the meaning of each word, think, analyze, and form the understanding. The assumption says that the individual has the knowledge of each element of the set $\boldsymbol{h}^+$ and he knows whether any given activity is a member of the set $\boldsymbol{h}^+$ or the set $\boldsymbol{h}^-$.

This assumption is in line with real situations as the individual usually knows relevant steps or actions for certain activities. He also knows relevant impediments of each step.

The bundle I is defined in a similar way as the bundle H except that it includes the sub-activities of the interrupting activity e.g. when the bundle H represents studying a chapter in a book, the bundle I is daydreaming about a vacation. So, its members are the sub-activities of daydreaming.

The values $U(H')$ and $U(I')$ represent the utility values of the output H' and I', respectively. The model assumes that they are determined by the individual in the self-control stage, so in the extremely impulsive setting he already has this knowledge. He knows whether he prefers the output H' or the output I'. Similar to the case of supply and demand, only the knowledge of the relative level of the value $U(H')$ and $U(I')$ suffices. From the example, the individual manages to follow his plan and comes to the library to study. He decides already that he has to study. Here, the assumption says that such preference is aware at the time he is distracted by the urge to daydream.

A note to differentiate the output in the self-control stage, I'_{sc}, and the one in the extremely impulsive setting, I', might make it clearer here. The former is out of the scope of this study. When the individual walks to the library, a friend invites him to a party. The decision between the two choices is in the self-control stage as the party activity is clearly distracting, relevant, and significant. Because of this, it does not meet the conditions of the extremely impulsive setting. Right there, however, when he decides that from that moment on for the coming hours the preferred activity

is studying, he fixes his preferred task. So, the value $U(H')$ is the highest among the possible options, i.e. $U(H') > U(I'_{sc})$.

The output I' of the focus here is daydreaming. In fact, the individual usually does not consider it worth choosing at the time he makes the above decision in the self-control stage. Going to the party is much more tempting than the brief moment of daydreaming while studying. In general, the output of the impulsive activities is normally irrelevant and insignificant, so it is less preferred. Therefore, the assumption on relative preference between the value $U(H')$ and $U(I')$ is realistic.

Assumption 3(2) deals with the appropriate state of mind of the individual in the storyline at the time when he reacts. This ensures that the individual is sufficiently alert, conscious of the related elements in Assumption 3(1) and the related options in Assumption 3(3), and ready to react and allocate his mental supply to either the activity h or the activity i. Assumption 3(2) neither violates Condition EIS2 (Seemingly Irrelevant) nor Condition EIS3 (Seemingly Insignificant) even if it might initially seem so. In reality, Assumption 3(2) comes into play in different intensity. With its full force, it violates Conditions EIS2 and EIS3. Then there is no more EIS and all falls into the scope of self-control. Here, the assumption only calls for a moderate level in a way that the individual has sufficient conscience to know that however insignificant and irrelevant the activity seems, it is significant and relevant. The assumption is arguably realistic as many individuals concentrate more and get less distracted when they are aware that they work on important tasks.

Assumption 3(3) concerns two issues: the right reaction and the right time. To see if the right reaction part is realistic, it is postponed until the proof of the forthcoming proposition. On the right time, the argument is also justified as the total processing and reaction time can be saved from mental preparation, alert conscience, and planned reaction.

Overall, Assumption 3 ensures that the individual has the right knowledge regarding the situation at hand and is sufficiently alert so that he can evaluate the situation and react optimally.

Grounded by Assumption 3 and from Definition 3, the optimal reaction strategies follow:

Proposition (Reaction Strategies in the Extremely Impulsive Setting):

1) When there is one key activity, respond to the key activity.

2) When there are two key activities or no key activity and the total mental supply is available for one activity, respond to the activity with the matched supply.

3) When there are two key activities or no key activity and the total mental supply is available for both activities or not available for any, respond to the activity which leads to higher utility.

To show the above proposition, all the possible cases are considered below:

Table 2.3 Reaction Strategies

h	I	S_h vs. D_h	S_i vs. D_i	$U(H')$ vs. $U(I')$	Strategy	Reason of choosing h or i.
$h \in \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$\geq$	$\geq$	$>$	c	h, as $U(H') > U(I')$.
$h \in \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$\geq$	$\geq$	$<$	c	i, as $U(H') < U(I')$.
$h \in \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$<$	$\geq$	$>$	b	i, as $S_h < D_h$.
$h \in \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$<$	$\geq$	$<$	b	i, as $S_h < D_h$.
$h \in \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$\geq$	$<$	$>$	b	h, as $S_i < D_i$.
$h \in \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$\geq$	$<$	$<$	b	h, as $S_i < D_i$.
$h \in \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$<$	$<$	$>$	c	h, as $U(H') > U(I')$.
$h \in \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$<$	$<$	$<$	c	i, as $U(H') < U(I')$.
$h \in \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$\geq$	$\geq$	$>$	a	h, as h is the key activity.
$h \in \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$\geq$	$\geq$	$<$	a	h, as h is the key activity.
$h \in \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$<$	$\geq$	$>$	a	h, as h is the key activity.
$h \in \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$<$	$\geq$	$<$	a	h, as h is the key activity.
$h \in \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$\geq$	$<$	$>$	a	h, as h is the key activity.
$h \in \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$\geq$	$<$	$<$	a	h, as h is the key activity.
$h \in \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$<$	$<$	$>$	a	h, as h is the key activity.
$h \in \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$<$	$<$	$<$	a	h, as h is the key activity.
$h \notin \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$\geq$	$\geq$	$>$	a	i, as i is the key activity.
$h \notin \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$\geq$	$\geq$	$<$	a	i, as i is the key activity.
$h \notin \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$<$	$\geq$	$>$	a	i, as i is the key activity.
$h \notin \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$<$	$\geq$	$<$	a	i, as i is the key activity.

Table 2.3 (Continued)

h	I	S_h vs. D_h	S_i vs. D_i	$U(H')$ vs. $U(I')$	Strategy	Reason of choosing h or i.
$h \notin \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$\geq$	$<$	$>$	a	i, as i is the key activity.
$h \notin \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$\geq$	$<$	$<$	a	i, as i is the key activity.
$h \notin \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$<$	$<$	$>$	a	i, as i is the key activity.
$h \notin \boldsymbol{h}^+$	$i \in \boldsymbol{i}^+$	$<$	$<$	$<$	a	i, as i is the key activity.
$h \notin \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$\geq$	$\geq$	$>$	c	h, as $U(H') > U(I')$.
$h \notin \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$\geq$	$\geq$	$<$	c	i, as $U(H') < U(I')$.
$h \notin \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$<$	$\geq$	$>$	b	i, as $S_h < D_h$.
$h \notin \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$<$	$\geq$	$<$	b	i, as $S_h < D_h$.
$h \notin \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$\geq$	$<$	$>$	b	h, as $S_i < D_i$.
$h \notin \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$\geq$	$<$	$<$	b	h, as $S_i < D_i$.
$h \notin \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$<$	$<$	$>$	c	h, as $U(H') > U(I')$.
$h \notin \boldsymbol{h}^+$	$i \notin \boldsymbol{i}^+$	$<$	$<$	$<$	c	i, as $U(H') < U(I')$.

Justifications of the three strategies:

Strategy a: One key-activity.

Consider the case of $h \in \boldsymbol{h}^+$, $i \notin \boldsymbol{i}^+$; $S_h \geq D_h$; $S_i \geq D_i$; $U(H') > U(I')$.

Proof: As the activity h is a member of the bundle H, reacting to the activity h contributes to the completion of the bundle H. Likewise, the activity i is not a member of the bundle I, reacting to the activity i does not contribute to the completion of the bundle I.

Logically, the value $U(H') > 0$ and so reacting to the activity h contributes to an increase in utility through the output H' while reacting to the activity i does not. It is then better-off to react to the activity h. Q.E.D.

Strategy b: Two key activities or no key activity when the total mental supply is available for one activity.

Consider the case of $h \in \boldsymbol{h}^+$, $i \in \boldsymbol{i}^+$; $S_h \geq D_h$; $S_i < D_i$; $U(H') < U(I')$.

Proof: The activity h is a member of the bundle H, reacting to the activity h contributes to the completion of the bundle H. Likewise, the activity i is a member of the bundle I, reacting to the activity i contributes to the completion of the bundle I.

From the value $U(H') < U(I')$, reacting to the activity i would have yielded higher utility value. However, the given mental state condition $S_i < D_i$ signifies an under-supplied case (one of the states in the upper-right corner of Illustration 4). This violates Matching Condition (Condition R2). Thus, it is unfeasible to react to the activity i.

On the other hand, as the mental state condition is $S_h \geq D_h$, reacting to the activity h is feasible as the mental supply is sufficient.

As the value $U(H')$ is positive, reacting to the activity h contributes to an increase in utility through the output H'. It is then better-off to react to the activity h. Q.E.D.

Strategy c: Two key activities or no key activity when the total mental supply is available for both activities or not available for any.

Consider the case of $h \in \boldsymbol{h}^+$, $i \in \boldsymbol{i}^+$; $S_h \geq D_h$; $S_i \geq D_i$; $U(H') > U(I')$.

Proof: The activity h is a member of the bundle H, reacting to the activity h contributes to the completion of the bundle H. Likewise, the activity i is a member of the bundle I, reacting to the activity i contributes to the completion of the bundle I.

As the given mental state condition is $S_h \geq D_h$, reacting to the activity h is feasible as the mental supply is sufficient. Likewise, with the condition $S_i \geq D_i$, reacting to the activity i also matches the mental supply.

However, as the value $U(H')$ is higher than the value $U(I')$, reacting to the activity h contributes to a higher increase in utility through the output H'. It is then better-off to react to the activity h. Q.E.D.

CHAPTER 3

EMPIRICAL MODELS

The theory part of this study concludes by a set of proposed reactions to tackle against impulsive reactions in an extremely impulsive setting with an attempt to align these reactions with the rational ones. It suggests the activity that should be reacted to when the individual is doing an activity and suddenly encounters another one.

Though the proposition is logically justified, its validity rests on the assumption that the individual has full information of the situation. That is, while he encounters the impulsive activity, he has information on the related mental demand and mental supply variables, appropriate mindset and conscience; and reacts following the proposition. Equivalently, Assumption 3 states that $\ddot{I} = \{i_a, i_d, i_c, i_r\}$ or $S_i = \{a1, d1, c1, r1\}_i$.

To do that, the individual can prepare his mind before entering into the EIS. He should also control his reactions so that the four mental supply elements are all activated. In the previous chapter, the assumption is discussed as sufficiently realistic for a prepared mind. This chapter includes empirical models to search further for causes of mental supply and their determinants. Knowing these, one should be able to influence mental supply and react following the proposition.

The objectives of the econometric part are threefold: First, to find causes of mental supply. What makes it be in the form $S_i = \{a1, d1, c1, r1\}_i$? How much is due to awareness, predetermined reactions, self-control, and rational/bounded rational elements of an individual? Once these causes are identified, one should be able to influence mental supply and react optimally.

Second, to highlight the importance of awareness and predetermined reactions, the two key elements of mental supply, by showing that their presence are necessary for self-control and rational elements to take effect in the EIS. Without the former two elements, the latter ones are ineffective. In addition, findings on this issue will shed light on the sequence of the supply formation steps according to Assumption 1.

In the theory chapter, the model posits that the key to align the individual's impulsive reactions with his rational decisions lies in the validity of Assumption 3. These first two objectives aim to identify major causes of mental supply so that individuals are ready to react optimally in the extremely impulsive settings.

The third objective is to investigate further for determinants of the four elements of mental supply. Assumption 2 mentions that the existence of the information set is the key and it is predetermined outside the EIS, prior to impulsive reactions. The aim is to verify whether the existence of the information set falls under individual's control or it is merely exogenous.

In short, this chapter proposes three empirical models to justify the three assumptions.

3.1 Causes of Mental Supply

Assumption 3 posits that the information set at the time of reacting to the activity i is $\ddot{I} = \{i_a, i_d, i_c, i_r\}$, which yields mental supply $S_i = \{a1, d1, c1, r1\}_i$. This fully activated form of supply satisfies the reaction condition R2 (Sufficient Mental Supply) and ensures the minimum possible time T_i.

The theory guides four causes of mental supply: awareness, predetermined reactions, self-control, and rational. To study this issue, consider a mental supply $S_i = \{a1, d1, c1, r1\}_i$ to react to an activity i in the EIS at time $t1$. Let represent this by a dataset S_{it1}. A similar panel of information from another snapshot $t2$ is stored in a dataset S_{it2}. One may use their first differences to account for the omitted variables and test:

$$S_{it1} - S_{it2} = a \cdot (a_{t1} - a_{t2}) + d \cdot (d_{t1} - d_{t2}) + c \cdot (c_{t1} - c_{t2}) + r \cdot (r_{t1} - r_{t2}) + (u_{t1} - u_{t2})$$

or, in a simpler notation: $\Delta S = a \cdot \Delta a + d \cdot \Delta d + c \cdot \Delta c + r \cdot \Delta r + \Delta u$.

Then, to capture possible quadratic effects, the following setup can be used:

$$\Delta S = a{\cdot}\Delta a + d{\cdot}\Delta d + c{\cdot}\Delta c + r{\cdot}\Delta r + e{\cdot}\Delta a^2 + f{\cdot}\Delta d^2 + g{\cdot}\Delta c^2 + h{\cdot}\Delta r^2 + \Delta u.$$

Findings from the above tests will show explainable effects of the four causes on the mental supply. Each coefficient indicates partial effects on the left-hand side holding fixed all other factors. Those of the quadratic terms capture the decreasing and increasing marginal effects. Turning points can be calculated and may hint more insights.

Recall from Assumption 3, one expects all four causes to be significantly positive. The setups of the two above tests capture only direct effects while the setup in Section 3.2 captures both direct and indirect/interaction effects. The test objectives are slightly different but complimenting. With datasets from different snapshots of time, these tests may reveal some insights on an evolution of effects from each cause.

3.2 Importance of Awareness and Predetermined Reactions

Assumption 1 lays down mental supply formation sequences: starting from awareness, predetermined reactions, self-control and rational/bounded rational respectively. While Table 2.2 and Condition R2 (Matching) show all possible matching results, the first two elements: awareness and predetermined reactions, the highlights of our study, arguably play a major role in determining mental supply sufficiency in the EIS. By acting as a bridge to the less rapid counterparts, their presence is necessary for self-control and rational elements to take effect in the EIS.

To verify such claim, consider testing:

$$S = \boldsymbol{\beta}{\cdot}\boldsymbol{(a,d,c,r)} + u$$

where vector $\boldsymbol{\beta}$ contains the coefficient terms and vector $\boldsymbol{(a,d,c,r)}$ represents sixteen different permutations of each binary mental supply elements. The two vectors could be partitioned into two parts. The first part, $\boldsymbol{\beta}_{a1d1}$, contains the four terms which

elements *a* and *d* are both active. The second part consists of the twelve others which at least one of these two elements is inactive.

Similar to the test in Section 3.1, the quadratic terms could be included in the setup to capture their interactions with direct and indirect/interaction effects. In any case, the test aims to verify that the coefficients of the *non-*$\boldsymbol{\beta}_{a1d1}$ terms are not different from zeroes, and those of the $\boldsymbol{\beta}_{a1d1}$ terms are not different from ones.

3.3 Determinants of Mental Supply Elements

Now that more is known about the causes of Assumption 3 and Assumption 1 through the above tests, next is to study Assumption 2. Similar to the above tests, the ultimate objective is not solely to verify the validity of the assumption but eventually to influence it.

Assumption 2 posits the existence of an information set $\ddot{I} = \{i_a, i_d, i_c, i_r\}$ which underlines the presence of the four mental supply elements. The set falls beyond the individual's control in the EIS as it is endogenously predetermined in the self-control stage. From the theory, it can be deduced that the individual has full control over this issue in the self-control scope. Hence, this test aims to check whether this is indeed the necessary and sufficient condition to activate the mental supply elements in the EIS.

To verify the claim, using the notation of Definition 4, consider:

$$\Delta \boldsymbol{p}_{iEIS} = \boldsymbol{z} \cdot \Delta \boldsymbol{[i_p \in \ddot{I}]}_{sc} + \Delta u$$

where vector $\Delta \boldsymbol{p}_{iEIS}$ represents the differences of the two panels of the element p_i as per Definition 4, captured at different snapshots of time, for the same individual. Vector $\boldsymbol{z}$ contains the coefficients of its adjacent term. The term $\Delta \boldsymbol{[i_p \in \ddot{I}]}_{sc}$ captures the first differences of the two time-differing panels of vector $\boldsymbol{[i_p \in \ddot{I}]}_{sc}$.

For example; when the process *p* is awareness, the binary dependent variable a_{iEIS} is zero when awareness of the event *i* is inactive in the EIS; the value is one when it is active. Likewise, the terms $\boldsymbol{[i_a \in \ddot{I}]}_{sc}$ are all zeros when awareness of the event *i* is not predetermined in the self-control stage. The values are all ones when it is.

The coefficients of each mental supply elements, vector z, should be no different from unities and Assumption 2 is strongly supported. In this case, the individual's predetermination of mental supply elements in the self-control stage directly dictates their activation in the EIS.

3.4 Possible Applications

Consider the following statistics before turning to some possible applications:

Table 3.1 Road Accident Cases

(unit: persons)

Year	Number Reported	Related Damage Amount in THB	Damage Types		
			Death	Serious Injury	Minor Injury
2007	101,752	4,620,398,166	12,492	15,989	63,040
2008	88,689	5,415,524,563	11,561	12,871	58,188
2009	84,806	3,815,520,899	10,717	10,113	51,883
2010	83,220	396,220,581	7,661	3,560	14,769
2011	68,296	610,686,128	9,060	4,047	17,123

Source: Office of the National Economic and Social Development Board, 2013e.

Table 3.2 Offenses and Crimes Records

(unit: persons)

Year	Offense Against the Person	Crimes Against Property	Crimes Related to Drug	Total
2007	39,448	73,022	141,820	254,290
2008	33,483	67,188	202,852	303,523
2009	32,670	59,509	236,042	328,221
2010	29,253	56,798	266,010	352,061
2011	23,993	47,285	320,972	392,250

Source: Office of the National Economic and Social Development Board, 2013c.

Table 3.3 Cases to the Juvenile Observation and Protection Center by Ground of Offense

(unit: persons)

Ground of Offense	2007	2008	2009	2010	2011
Total	51,128	46,981	46,371	44,057	39,174
Offense against property	14,764	12,658	10,073	9,742	8,430
Offense against the person	7,784	6,661	6,388	5,474	4,424
Sexual assault	2,154	1,916	2,538	1,812	1,584
Offense against peace, freedom, reputation, and governance	3,247	2,989	2,407	2,300	1,766
Offense related to drugs	10,279	11,207	12,352	14,695	15,570
Offense related to weapon and explosive weapon	3,650	3,251	3,413	2,889	2,458
Others	9,250	8,299	9,200	7,145	4,942

Source: Office of the National Economic and Social Development Board, 2013b.

Table 3.4 Arrest Cases by Reason and Motivation

(unit: persons)

Reason and Motivation	2007 2	008 2	009 2	010 2	011
Total	51,128	46,981	46,371	44,057	35,049
Mental sickness	79	73	91	75	32
Fight and dispute	2,432	2,154	2,250	2,084	740
Economic status	3,505	3,182	3,188	3,011	876
Forced by other person	1,870	1,364	1,607	1,472	806
Family constrains	3,060	2,487	2,983	2,599	2,418
Influence from friend(s)	20,215	18,774	18,499	17,535	15,769
Ignorance, being benighted, and being unaware	5,539	4,748	5,071	4,682	3,305
Being Impetuous	7,839	8,582	6,978	7,145	7,038
Others	6,589	5,617	5,704	5,454	4,065

Source: Office of the National Economic and Social Development Board, 2013a.

Table 3.5 Population Who Exercise Regularly, 2011.

(unit: 1,000 persons)

Subgroup	Number of Population, Age > 11			Number of Population Who Exercise		
	Total	Male	Female	Total	Male	Female
Total	57,688	28,140	29,549	15,074	7,697	7,377
Age 11 - 14	7,673	3,936	3,737	4,608	2,521	2,087
Age 15 - 24	20,821	10,638	10,183	8,319	4,929	3,390
Age 25 - 59	70,493	34,478	36,014	13,361	6,239	7,122
Age >= 60	16,390	7,227	9,164	3,861	1,705	2,156
Bangkok	5,895	2,696	3,199	1,859	923	936
Central region	13,814	6,685	7,129	3,034	1,614	1,420
Northern region	10,675	5,245	5,430	3,073	1,549	1,524
Northeastern region	19,487	9,656	9,831	4,767	2,390	2,377
Southern region	7,818	3,858	3,960	2,341	1,221	1,121

Source: Office of the National Economic and Social Development Board, 2013d.

Table 3.6 Total Death from Important Diseases*

(unit: persons)

Subgroup	2007	2008	2009	2010	2011
Total death from all diseases	393,255	397,327	393,916	411,331	414,670
Cancer	53,434	55,403	56,058	58,076	61,082
Accidents and Poisonings	35,661	34,851	35,304	32,861	33,868
Heart diseases	18,452	18,820	18,375	18,399	20,130
Lung and lung-related diseases	14,179	14,542	14,542	16,369	16,884
Stroke	12,995	13,133	13,353	17,540	19,283
Diabetes	7,686	7,725	7,019	6,855	7,625
Suicide	3,756	3,778	3,787	3,761	3,776
High Blood Pressure	2,291	2,463	2,295	2,478	3,664
AIDS	5,522	4,685	4,046	3,638	3,758

Source: Office of the National Economic and Social Development Board, 2013f.

Note: * are those that are preventable but the annual death record increases

Tables 3.1 to 3.6 show statistics from different subjects: accident, crime, and health. These statistics illustrate few concrete examples of this study's applications. Tracing from their footprints, these statistics come from the cumulative results of decisions and reactions. Somehow causes of these results share some things in common. Looking at them from the three stages according to Figure 1.1, there causes come from impulsive reactions, self-control, and planning.

Complicated in reality and oversimplified in theory, perhaps; but a possible unified explanation goes like this: an outcome of any issue comes from individual's reactions. Within the scope of this study, impulsive reactions come either from the mental output H' or I'. Looking back to where it starts and recall Definition 1 for the definitions of outputs H' and I'. Mental output comes from its input, which results from matching between mental demand and mental supply. The strategy is proposed to select the optimal mental input and suggest how to reinforce the mental supply. Thus, impulsive reactions are now under control.

3.5 Conclusion

While it is common to observe undesirable intuitive reactions in daily life, existing models on rational choice and self-control do not provide sufficient explanation on the processes which generate these impulsive reactions. Hence, they seem to fall outside the individual's scope of control. Seen initially as exogenous, with time, these impulsive reactions become automatic. They conceal other possible reactions and limit choices.

A model is proposed to explain the reaction-generating processes of the impulsive reactions in the extremely impulsive setting, between the bounded rationality and self-control spheres, and show that those impulsive reactions can be handled optimally.

The model shows mental supply generation processes. When the supply suffices, the intended reaction is carried out. It suggests reacting to the activity which is feasible and yields higher utility, and contains the proofs that the proposition is indeed utility enhancing.

As the proposition rests on the assumption of full information, the issue thus shifts to mental supply sufficiency as the key determinant of the impulsive reactions. The assumption of supply formation indicates that mental supply comes from awareness, predetermined reactions, self-control, and rational causes. The assumption of supply threshold says that these causes are endogenously predetermined in the self-control stage. Relevant empirical models are proposed to validate these assumptions.

The study concludes and suggests possible uses in different areas e.g. education, accident prevention, crime reduction, and health improvement.

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