Why Do Seminar Leaders Not Upload Their Solutions?

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Abstract

Almost every bachelor student has asked himself this question at one point while copying notes from a blackboard: Why is this not available online? Often given reasons are pedagogic ones or lack of attendance in case of upload. If students are rational however, seminar attendance is chosen optimally and should therefore be of no concern. Yet, many universities do not make the solutions to the exercises they give in seminars available online. While there is a multitude of possible reasons, this thesis sets out to investigate if students’ lack of self-control can explain this paternalistic behavior from universities. In other words, can withholding the solutions incentivize students to overcome their procrastination, increase seminar attendance, reduce student stress and improve academic performance?

The question is approached by modelling a quasi-hyperbolic discounter with logarithmic preferences as student who takes the tradeoff between leisure and studying over two periods with the exam in the third period. The first period represents seminar attendance and the second represents preparation time near the exam, and the lack of solution availability is implemented as a flat penalty on study productivity in the second period.

The result of the model is quite clear: While seminar attendance and, for students with lack of self-control, also total study time increases under withheld solutions, both welfare and exam performance are decreasing with increasing penalty for all possible students under sufficiently low values for the penalty. The cases of large penalty values is also examined with reservations.

Ironically, the goal of withholding the solutions is to increase academic performance and fight procrastination, yet this project finds that students enjoy a higher utility from leisure and perform worse in the exam if solutions are withheld.
Preface

First, I want to thank my supervisor, Prof. Kjell Arne Brekke. He did not only provide me with insights into behavioral economics, but also into the “other side of the seminar”. I am grateful for my father’s endurance, for my mother and her always helpful questions, and for Heidi Åmot-“playing economic ball” with me when I got stuck. This project also had help from two German Faculty Heads as well as a seminar leader at the University of Oslo.

Last but not least I send my gratitude to the Ludwig-Maximillians-University in Munich and especially Prof. Monika Schnitzer and her chair, at which I took my first ever course in (micro-)economics. Ironically, that course was not only the one that got me hooked on economics- its seminars also made me ask a certain question: why do seminar leaders not upload their solutions?
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1 Introduction

In my very first semester of economic education I attended the compulsory microeconomics course. I had a great teacher and I found it interesting to learn about the rationality of the homo oeconomicus and his behavior patterns. It was the same chair that made me question the very same teaching, as the seminars belonging to that course offered little more than copying the solutions to diverse math problems, which the seminar leader had just written on an overhead projector. Two universities and a behavioral economics course later, I get to ask the question: if students are rational, why would the economic faculty not make use of what I have learned to call a “Public Good” by making the solutions freely available on the universities’ internet presence?

The practice of withholding the solutions has been widespread across two economic faculties I have studied at, namely The University of Oslo in Norway and the Ludwig-Maximillians-Universität in Munich, Germany. During the bachelor program in Munich, the only time I received a solution was when the teacher had not been able to finish the workload for a seminar, and even then, it was rare to have it uploaded. In Oslo, I attended one seminar where the solutions were handed out during the seminar or by making an appointment with the teacher. Apart from that, all the courses I attended at the mentioned universities were without access to the solutions. I have furthermore inquired with the heads of two major economic faculties in Germany about the practice via email. Both confirmed that it was common practice among their faculties. The main reasons stated are that solution availability were to lead to strong attrition in the seminar. Other reasons named were pedagogic considerations and a surge in simple and avoidable mistakes in the exam. With the reasoning from the basic microeconomics course, attrition does not present a plausible reason. The student’s decision to attend or not should be optimal and there would be no reason for paternalism from the university. However, as the practice of not uploading is widespread, there must be some reason for withholding information from the students.

Due to the advancement in behavioral economics over the last decades I turned to examine if the lack of student self-control might give cause for the university to withhold the solutions with only the student’s best in mind. In other words, the seminar leader knows that the student has a self-control problem and incentivizes the student to attend the seminar. Spending study time early could also help the student to overcome procrastination issues. Still, withholding the solutions comes at a cost, as all students face higher cost for obtaining the relevant information due to imperfect notes and attendance. Procrastination in itself has been shown to have its own cost and is worth to be
considered. Think of the students in the exam period who suffer stress from long days in the library and studying schedules including “all-nighters” as they have delayed their studying for too long.

This thesis sets out to explore if the student’s self-control problem can be cause for a benevolent teacher to not upload the solutions, despite the incurred cost of paternalism. This is done by modeling the student’s decision as a matter of time allocation with inconsistent temporal preferences, inspired by Caitlyn Fischer’s working paper (Fischer, 1999 B). The student is a sophisticated, quasi-hyperbolic discounter similar to common literature (Laibson, 1997) (O'Donoghue & Rabin, 2001). The model examines two decision periods in which he can spend his time on leisure, which gives him logarithmic utility, while all unused time is counted as time spent studying. If the solutions are not available however, study time in the second period is subjected to a flat productivity penalty and is thus less effective, creating an incentive to study in the first period. The withholding consequently works against the self-control problem and procrastination. The decision process is modeled as a sequential game as each period’s self is treated like an individual.

I find that neither welfare nor exam performance can be improved by the withholding of studying material. On the contrary, overall student welfare and academic performance are decreasing with increasing penalty. The stress from procrastination might be eased as students receive more utility from leisure and less from academic performance. The model does however show that seminar attendance is higher under withheld solutions. This in turn could be a relevant reason for seminar leaders to not upload the solutions as they might believe that seminar attendance is the lone key to exam performance or that they prefer to answer a question once in the seminar instead of multiple times in emails and appointments.

The general structure of university courses and its translation into a mathematical model is dealt with in chapter two. It also contains a detailed explanation of how the withholding of solutions creates the incentive. Chapter three contains the formal analysis of the main model. Chapter four gives insight into the model results by showing graphs of a model-simulation. Chapter five deals with a special case that has limited explanatory value. I conclude in chapter six with some interpretations of the results presented.
2 The Relation Between Students and Seminar Solutions

2.1 Taking a Course

I will describe the way a typical course worked in the mentioned universities in a sufficiently abstract way to create a foundation for economic analysis. A course consists of two classes of different sizes, a lecture and a seminar. The lecture is usually a front held presentation by the professor introducing the next chapter of the curriculum. The seminar, usually held by a PhD candidate or research assistant, entails the presentation of the solutions to the weekly exercise sheet that addresses the week’s lecture’s topic. Students are encouraged to try the exercises on their own beforehand. The grade is determined solely by the students’ performance in the exam at the end of the semester and students have a lecture free studying period between the end of classes and the exam. The tasks in the exam are usually analogous to the weekly assignments. Acquiring the knowledge necessary to solve the assignments from other sources such as textbooks is more time consuming as textbooks contain a broader spectrum that needs to be filtered for the relevant information. To have attended the seminar or gained access to the solutions is an advantage in the studying period, as the necessary level of understanding can be reached in shorter time. The next preparation step for the exam is then to solve older exams which can be used to practice what has been learned from the assignments.

2.2 The Rational Student

Over the course of their academic career, any student faces the decision of time allocation. Should he attend the seminar or pack up his skies and enjoy the winter sun in the cross-country ski tracks around the city? In more general terms, the student decides between spending his time on studies and attending classes or on leisure and other activities, for example working a job. Leisure and studying are assumed to be substitutes. It is further assumed that the student cares about his
academic success and in addition to that he measures it mostly through his exam performance\textsuperscript{1}. It can be increased through knowledge generation during studying time.

The rational and perfectly informed student chooses the allocation of time between all occupations that grants him the highest overall utility. This also includes the decision of how many hours he spends attending the seminar. Attending the seminar means having better notes, though it is very hard to attend all seminars and obtain perfect notes of the content. The student is aware of how good the seminar presentation helps him to prepare for the exam and how much leisure he will miss out on in the future for skipping the seminar today. The seminar leader has a strong influence on this decision. Not only is he the determining factor in presentation quality, but he also decides whether to make the exercise sheet solutions available or not. Students will have a ceteris paribus improvement in their utility with available solutions. Having the same time allocation, the student now has a better grade in the exam as his studying has become more effective. The student’s preferences determine the strength of substitution and income effects. The student has more time while achieving the same grade but the price of taking more leisure has increased as an even better grade requires less time\textsuperscript{2}.

Regardless of his preferences it is likely that seminar attendance will be dropping for the individual student as well as for the whole seminar as the only reason left to attend the seminar is the added value of oral presentation and the live presence of the seminar leader, whereas before attending the seminar affected all the time spent studying. Given that students learn in heterogeneous ways some might find this added value to be sufficient to attend while others will shift their study time away from the seminar if the solutions are available. The student decision is first best and there is no reason for paternalism\textsuperscript{3}. This leaves us with the solution puzzle: Why do seminar leaders not upload their solutions?

\section*{2.3 The Not So Rational Student}

A self-control problem exists if an individual shows behavior that is not in its own perceived self-interest. A student for example that must hand in an assignment on Thursday might delay writing

\textsuperscript{1} It is conceivable that the actual interest patterns of students in academic success are more complicated than this. Exam performance is however important enough to neglect the other imaginable factors such as deeper understanding of the subject matter, personal development etc.

\textsuperscript{2} Under the assumption that good grades are not a Giffen good.

\textsuperscript{3} This is under the assumption that the upload decision is taken in order to maximize student utility. If the decision is made in order to maximize exam performance, good grades must not be a Giffen Good for the statement to be true.
it on Monday and again on Tuesday, even though he knows that he will then miss out on the family dinner on Wednesday he was looking forward to. The topic has been discussed in the literature in many other disciplines as well as economics. George Ainslie sums up literature from different fields of social sciences and concludes that the reason for choosing a smaller, poorer or more disastrous alternative lies in the distortion of the valuation of the consequences over time- distant ones seem less important than close ones. This might lead to choices that are regretted by the individual as time progresses (Ainslie, 1975).

In their article, E.S. Phelps and R. A. Pollak use present biased intertemporal preferences to model intergenerational transfers, introducing an additional discount factor to Samuelson’s classic Discounted Utility Theory. The clue of the preferences is that the relevance of every possible occurrence in the future is diminished by the same rate (Phelps & Pollak, 1968). The model has since been adapted to individuals by many behavioral economists. Carolyn Fischer shows that so called quasi-hyperbolic discounting can explain procrastinating behavior without using unusual parameter calibrations compared to the standard discounted utility model (Fischer, 1999 A). She furthermore shows that this procrastination as a behavior is harmful to the individual’s utility as leisure should be smoothed over time and procrastination implies that the time for finishing the task is clustered right before the deadline in case of a fixed reward. If the reward is however dependent on how much time was spent working, quasi-hyperbolic discounting leads to a reduced reward compared to the choices of an individual with time consistent preferences (Fischer, 1999 B). To overcome such problems, individuals can implement commitment devices. These are ways to have influence on your future self’s decision process. Examples for this are the tendency to group up to do an unpleasant task such as studying or training, going to a restaurant that does not offer unhealthy food, taking bets against one’s own procrastination, Christmas clubs, and illiquid assets. Commitment devices have been a significant part of recent literature and studies (Bryan, Karlan, & Nelson, 2010). Dan Ariely and Klaus Wertenbroch show in their paper that students, if given the chance to set deadlines for themselves, make use of commitment devices to prevent themselves from falling to procrastination. They also find that this behavior does increase their performance (Wertenbroch & Ariely, 2002). This implies that students are willing to reduce the size of their set of possible actions- as they put deadlines on themselves- to overcome their self-control problem.
This presents a possible explanation to the solution puzzle. The teacher withholds the solutions in the student’s own interest to incentivize them to spend time on university early in the semester as compared to procrastination. Assuming perfect availability of solutions and that study time in the semester is at least as good as study time in the library, students will to some extent procrastinate their study time to the end of the semester. According to Fischer’s findings, they will also perform worse in the exam. (Fischer, 1999 B) The student plans to study every day after today but then, come tomorrow, repeats this process of delaying the task. He does this until the time to the exam is so short that the discounted reward of better grades through studying is bigger than the utility gain of excising more leisure. He would however have preferred smooth leisure consumption over time. It is for this reason that the self-control problem is harmful to the student. Withholding the solutions increases the impact of time spent in the seminar as it grants access to solutions. The student will attend the seminar more often than in case of available solutions. It is conceivable that the time newly spent on the seminar however crowds out the studying time to some extent. This is the possible justification for seminar leader paternalism.

Withholding the solutions comes at a cost. As laid out earlier, students might still choose to not attend the seminar perfectly and will therefore sustain a decreased studying efficiency. As a result, they will study less while increasing their leisure. This is especially true for those students who do not have a self-control problem, as they are exposed to an increased price of good grades. These students however do not tend to procrastinate and shifting overall study time towards the seminar is less costly for them as for the self-control troubled students.

Those students who do not have a self-control problem are subjected to a loss of utility by the lack of available solutions. An affected student, whose time allocation plays out the way he planned it at the beginning of the semester, will ceteris paribus have a decreased exam performance. Depending on preferences, he will study less and spend more time on leisure. The next two chapters sets out to model the students time allocation process and answer the question if withholding the solutions can improve the student’s self-control problem.

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4 Again, under the assumption that good grades are not a Giffen good.
3 Model

3.1 Overview

The model consists of a representative student that allocates his limited time in each of the two periods, inspired by Caitlyn Fischer’s model of time as an exhaustible resource (Fischer, 1999 B). The first period represents the seminar, while the second period represents the exam preparation period. Study time in period one correspondingly represents seminar attendance while study time in period two can be seen as time spent in the library, reviewing material. The student maximizes his leisure while all time not spent is counted as study time. In the third period the student takes the exam and its score is based on how much he studied, though he does not have any decisions to take in that period.

The student has a self-control problem which manifests as time inconsistent preferences. More specifically, the student is a quasi-hyperbolic discounter utilizing the $\beta - \delta$ model. The model was first introduced by Phelps and Pollak (1968) to model intergenerational altruism and adapted to individual decisions for the first time by Jon Elster (1979) and has since become a broadly used method of modelling hyperbolic discounting. Laibson and others have broadly explored its theoretical use and explanatory power. Relevant to this paper is especially the description of procrastination—the anomaly that an individual’s intertemporal preferences lead to a decrease in utility compared to the plan of a previous point in time through delaying tasks. O’Donoghue and Rabin (1999) use the $\beta - \delta$ model to show that self-control problems can lead to harmful procrastination. On the same topic, Caitlyn Fischer shows in the series of two working papers that quasi-hyperbolic discounting is a theoretical explanation to procrastination with much more realistic parameter values than using exponential discounting (Fisher 1999A, 1999B). A discussion of different models of temporal preferences and their anomalies is provided by Frederick, Loewenstein and O’Donoghue (2002).

An alternative approach to quasi-hyperbolic discounting is Daniel Reads sub-additive discounting (Read, 2001). He shows that division of period into smaller periods can change the overall discounting rate in a manner similar to hyperbolic discounting. Quasi-hyperbolic discounting more widely used due to its tractability and simplicity. These are also the reasons for using the $\beta - \delta$ model in this project.
The effectiveness of all studying done in the second period depends on the solution availability. Lack of solutions imposes a negative effect on the productivity in the second period compared to the first period. The student has more trouble studying in the library as he needs to gather information in less efficient ways than the solutions. These are assumed to be the best way to prepare as the exam is usually analogous to the exercise tasks. The effect is modeled as a multiplicative penalty factor on period two productivity, with a value one implying that the student takes the double amount of time to achieve the same amount of knowledge. Zero indicates that the solutions are available and there is no difference between the periods in terms of studying productivity. The model is then used to judge if the withholding of the solutions can have a positive effect on student welfare and exam performance. Total study time, seminar attendance and the decomposition of utility will also be examined.

The next section discusses possible pitfalls as well as the reasoning behind how the model is set up. Section 3.3 then introduces and discusses the formal parts of the model. In section 3.4, the backwards induction is solved and in 3.5 the value function is analyzed to examine the effect of the penalty on the student.

### 3.2 General Discussion

**Who uploads the solutions?**

There are certain aspects that might be relevant to the problem, which will be excluded from examination to focus on the main question. The decision to upload the solutions is not necessarily made by the seminar leader, but might be done on a different level, for example by the professor, the convent of chairs, the department, or by the head of the faculty. Given that these institutions and persons are all subjected to different levels of information or other mechanisms, it is possible that something in this process affects the upload decision. Be that as it may, the main question of this thesis is if student procrastination can be eased through solution-paternalism. It is of low importance who makes the decision and it is assumed that the seminar leader decides.

**What does the Seminar Leader care about?**

It is safe to say that the seminar leader is interested in the student’s wellbeing in some form. The model examines two possibilities which seem most important to student life, namely exam performance as a result of study time, and student welfare as a result of leisure and exam
performance. Exam performance is not a necessary or sufficient criterion for student wellbeing, yet it is a very evident metric to the seminar leader and can be easily observed. Student welfare on the other hand is more difficult to observe by the seminar leader, albeit being the better criterion for student wellbeing. Whereas exam performance is merely the sum of study time in this model, student welfare also takes into account how much the student is impacted in his leisure choice. Both values will be examined in the model.

It is also possible that the seminar leader has an interest in seminar attendance. Not only is seminar attendance the easiest to observe out of all the results this model offers, it is also not unheard of that seminar attendance causes students to perform better in the exam. Literature on the relation between attendance and academic performance is ambiguous. Study results range from a positive effect of attendance over no effect of attendance on performance to the finding that study time instead of attendance is the relevant variable that predicts academic performance. Andrietti and Velasco give a good overview over the research done on the effect and contribute a penal data analysis on study time versus attendance themselves. (Andrietti & Velasco, 2015) The model used in this project will also yield results on attendance and study time, as student time allocation to period one is seen as (seminar) attendance, while study time in period two represents time outside of lectures and seminars.

3.3 Specific Discussion

Preferences

The student receives utility from his leisure in periods one and two, $l_1$ and $l_2$ and his exam performance $E$. It is assumed that the utility from different periods is independent and additive. Furthermore, the student has quasi hyperbolic intertemporal preferences, represented by the $\beta - \delta$ model (Phelps & Pollak, 1968). Given the time inconsistent nature of the preferences, every period’s instance of the student will be treated as a separate individual. The student is past his first semester and therefore knows about his intertemporal preferences. Hence, he can be treated as a sophisticated decision maker. The maximization problems are then as follows, with $U_i$ depicting the utility of period $i$’s self. Leisure can naturally neither take negative values nor exceed the period time constraint $T$.

$$U_1 = U(l_1) + \beta \delta U(l_2) + \beta \delta^2 U(E(l_1, l_2))$$
\[ U_2 = U(l_2) + \beta \delta U(E(l_1, l_2)) \]

\[ l_1, l_2 \leq T \]

\[ l_1, l_2 > 0 \]

\[ \beta, \delta \in (0, 1] \]

It is implicitly assumed that the student’s utility of leisure is the same not only for both periods, but also for the exam performance. Note that the student only decides on his leisure consumption in periods one and two and that there is no decision in period three.

All utility functions are logarithmic, including the utility from exam performance.

\[ U(l_i) = \ln(l_i) \]

\[ U(E(l_1, l_2)) = \ln(E(l_1, l_2)) \]

Logarithmic preferences are simple in handling while strictly positive slope, concavity, and diminishing returns are fulfilled. Another important feature is that the marginal first unit of a good has infinite marginal utility due to the nature of the logarithm. For the model, this implies that the student will study a positive amount in at least one period to rake in the infinite marginal utility of a little work on exam performances. This can be viewed as getting a passing grade, while the first units of leisure can be seen as getting sleep or the necessary income to sustain studies.

**Exam Performance, Productivity and the Penalty from Lack of Solutions**

The student is assumed to spend all his time studying except for when he spends it on leisure. As a result, the study time of a period is equal to the time constraint less the period’s leisure. The production function is different for the two periods. In the first period, one unit of study time generates one unit of exam performance. In the second period, the productivity is influenced by the availability of solutions. The effect on productivity by the lack of solutions is implemented as a flat multiplier on period two productivity. The exam performance \( E \) then is:

\[ E(l_1, l_2) = T - l_1 + \frac{1}{1+\lambda}(T - l_2) \quad (1) \]

For \( \lambda = 0 \), the scenario of period one and two’s productivities are the same and normalized to one. For values of \( \lambda \) higher than that, the second period’s productivity is \( \frac{1}{1+\lambda} \). This puts emphasis on the
size of $\lambda$. At $\lambda = 1$ productivity in period two is $\frac{1}{2}$, the student thus needs to spend the double amount of time to achieve the same result as if he had been studying in period one. Relevant values of $\lambda$ will be assumed to be below $\lambda = 1$. $\lambda = 0$ is viewed as the case of uploaded solutions- It neither matters whether the student attends the seminar, nor does his allocation of time change his average productivity.

It can be argued that time in the seminar and time in the library have different productivities to begin with, especially in conjunction with heterogeneous students. However, it is not relevant to this model as the focus is on the effect of an induced difference of productivities between the two periods. The status quo productivities could have a ratio deviating from one, yet it is unlikely that the actual ratio value is relevant to the effect of a change in this ratio.

Values for $\lambda$ lower than zero are not examined. Such values imply that withholding solutions directly improves study productivity in the exam preparation phase represented by period two. This case seems unlikely- if the student had the solutions, he could decide not to look at them to gain the benefit.

Implementing the lack-of-solution cost as a productivity multiplier in period two can be reasoned with imperfect notes. Exams in bachelor economics courses often strongly resemble the exercise sheets given in the seminar. A viable method of exam preparation, which is assumed to happen in period two, is therefore to revise the seminar exercises. Even with perfect attendance to the seminar, it is doubtful that the student is able to replicate full understanding of the exercises in his notes. With notes being a less than perfect substitute for solutions, the productivity in the second period is smaller than under uploaded solutions. The time lost on searching and organizing alternative knowledge sources such as fellow students or textbooks can be argued for as examples for the reduced productivity. This line of reasoning becomes even more evident with limited attendance. Lower attendance leads to lower overall information in the notes as they need to be copied from a fellow student or the information has to be extracted from a textbook. Note that absence can be caused by reasons beyond the student’s short term influence, for example sickness, transportation, or working hours.

Defining the effect on productivity caused by the lack of solutions as a flat multiplier seems contradictory to the way the learning process of a course has been described above. The more the student attends the seminar, the more access he gains to the solutions thus being the more independent of the teacher’s decision whether to upload the solutions or not. Students will however
not attend all seminars even if they want to. This implies that a flat penalty multiplier has an effect similar to the one caused by not uploading the solutions in the real world. Modeling the penalty $\lambda$ as an inclining function of $l_1$ is a more realistic approach. It however strongly complicates the model. On one hand, it can be argued that this complication is not necessary as it would only increase the incentive to study in the first period. On the other hand, the results on welfare and exam performances do depend on numbers. Assuming that a penalty depending on $l_1$ instead of a flat $\lambda$ can create the same incentive with less effect on the actual productivity, this could change the outcome of the model. Despite these arguments, analyzing this particular possibility would be too extensive for the frame of this project.

**Why Studying In itself Must Be Boring**

The exam performance is modelled as the sum of the knowledge gained. Knowledge is gained through time-consuming studies. For the model, it is assumed that the act of studying is in itself utility neutral. The time allocation decision is however influenced by opportunity cost in foregone leisure and reward through the increased exam performance. While the idea of enjoying study time is not unimaginable, it would invalidate the paternalistic argument for not uploading the solutions. If students were to enjoy the seminar, being present biased would not decrease their attendance. Individuals with quasi-hyperbolic discounting tend to bring forward positive activities and delay negative ones. Hence, student self-control would not be a legitimate reason to incentivize attendance.

**Solutions Against Procrastination**

A $\beta - \delta$ discounter will procrastinate a well-defined task until the last moment possible and if the amount of work is variable, he will do less work than an individual without present bias (Fischer, 1999 B). Transferred to this model, the student will do the lion’s share of this work in the second period. In other words, he will not attend the seminar and slack through the first part of the semester to then use most of his daily time in the library right before the exams. Yet, students do attend seminars. The denial of uploaded solutions to non-attending students creates an incentive to attend the seminar. In the model, the change of productivity might force the student to spend more time studying in the first period and thereby counteract the negative effect of procrastination.

**Sophistication vs. Naiveté**
When dealing with inconsistent temporal preferences, the individual has to form expectations about how his future instances will behave. Sophisticated individuals have perfect foresight and know that they will have a present bias in the future (Laibson, 1997), whereas naïve individuals falsely suspect that their future instance will comply with their present plan (Akerlof, 1991). Partial naiveté describes individuals who know about their self-control problem, but fail to estimate its severity correctly (O'Donoghue & Rabin, 2001). The literature also finds that naïve individuals tend to delay unpleasant tasks like studying even further than sophisticated individuals. In their article from 2006, Lamendier and DellaVigna find that naiveté in individuals can explain certain procrastination-behavior on gym membership cancellation as study subject (2006).

This project employs a strictly sophisticated student as this type has the best grasp of his behavior and is intuitively more prone to incentives than a naïve student. That being said, the matter is of little relevance as both the naïve and the sophisticated student reach the same outcome for interior solutions. The student in the second period has no other choice than to react to the accumulated study time from the first period whether he is naïve or sophisticated. For the first period, it can be shown with simple maximization that the leisure values under naiveté are the same as under sophistication.

**Positive effect on Seminar Productivity**

It can be argued that if withholding solutions creates a negative effect on end-of-semester study time productivity, it also creates a positive effect on seminar attendance productivity as the notes taken then help in later study time. This can be added in the model as a productivity enhancing parameter for the first period. It is however natural to assume that this effect, depicted as $\gamma$ below, is smaller than the productivity penalty of lack of solutions, $\lambda$. In other words, going to the seminar and taking notes cannot yield more productivity per minute than actually studying with the solutions for one minute. Simulating a model with increasing productivity in period one does not provide cause for withholding the solutions. This assumption is can be written as

$$0 \leq \gamma \leq \lambda < 0.7$$

The equivalent to equation (1) is

$$E(l_1, l_2) = (T - l_1)(1 + \gamma) + \frac{1}{1 + \lambda}(T - l_2)$$
Simulating this model has led to the conclusion that the effect of withholding solutions on welfare and exam performance is not different in its sign.

### 3.4 Backwards Induction

#### 3.4.1 Introduction

The student is in conflict here with his own future interests, as he desires high leisure in period one from its own point of view. From the second period’s point of view however he wants to have more leisure in period two. It is therefore best to deal with the problem as if every period had its own individual instance of the student acting as an independent individual. With this assumption, the problem can be solved as a sequential game. The following subsections describe the process of finding a subgame perfect Nash equilibrium using backwards induction.

The model can result in a special case for large values of \( \lambda \) which will be discussed in a later chapter. For \( \lambda < \tilde{\lambda} \), the second period’s self will always choose the interior solution. For the rest of this chapter it will be assumed that \( \lambda \leq 0,7 \), as the real \( \tilde{\lambda} \) is unknown and simulation of the model shows that \( \tilde{\lambda} \) lies between 0,7 and 0,72. This ensures that the period two self will never use all his time for leisure. Note that a value of \( \lambda = 1 \) already implies that a student needs to spend the double amount of time for the same knowledge gain compared to solution availability.

\[
0 \leq \lambda \leq 0,7
\]

#### 3.4.2 Period Two Behavior

Period two’s self (short: P2) reacts to the leisure choice of period one’s self (short: P1) and therefore treats \( l_1 \) as a constant. P2 maximizes his utility over his leisure choice:

\[
\max_{l_2} U_2 = \ln(l_2) + \beta \delta \ln \left( T - l_1 + \frac{T - l_2}{1 + \lambda} \right)
\]

The first order conditions then are

\[
\frac{\partial U_2}{\partial l_2} = \frac{1}{l_2} - \frac{\beta \delta}{1 + \lambda} \left( \frac{1}{T - l_1} + \frac{T - l_2}{1 + \lambda} \right) = 0
\] (2)
Compiling the fractions leads to

\[
\frac{1}{l_2} - \frac{\beta \delta}{(T - l_1)(1 + \lambda) + T - l_2} = 0
\]

Multiplying with the denominator gives

\[
(T - l_1)(1 + \lambda) + T - l_2 - \beta \delta l_2 = 0
\]

Bracketing out \( l_2 \) yields

\[
-l_2(1 + \beta \delta) + T(2 + \lambda) - l_1(1 + \lambda) = 0
\]

Solving for \( l_2 \) we get

\[
l_2^* = \frac{T(2 + \lambda) - l_1(1 + \lambda)}{1 + \beta \delta}
\] (3)

Equation (3) depicts the interior solution of this maximization problem. P2 cannot consume more leisure than he has time, this equation has to be smaller or equal than \( T \). Simulation has shown that for sufficiently small values of \( \lambda < \sim 0.7 \), P2 will always play interior solution.

Derivation of equation (2) shows that the function is strictly concave in \( l_2 \). Equation (3) therefore depicts a maximum.

\[
\frac{\partial U}{\partial l_2} = -\frac{1}{l_2^2} - \frac{\beta \delta}{((T - l_1)(1 + \lambda) + T - l_2)^2} < 0
\]

3.4.3 Period One Behavior

P2 playing interior solution

For P1 predicting P2 to play the interior solution, his problem can then be described as

\[
\max_{l_1} U_1 = \ln(l_1) + \beta \delta \ln(l_2^*) + \beta \delta^2 \ln \left( T - l_1 + \frac{T - l_2^*}{1 + \lambda} \right)
\] (4)

Substitution of equation (3) and simplifying the argument of the third logarithm leads to the following problem:
\[
\max_{l_1} U_1 = \ln(l_1) + \beta \delta \ln\left(\frac{T(2 + \lambda) - l_1(1 + \lambda)}{1 + \beta \delta}\right) + \beta \delta^2 \ln\left(\frac{\beta \delta (T(2 + \lambda) - l_1(1 + \lambda))}{(1 + \beta \delta)(1 + \lambda)}\right)
\]

The derivative is then
\[
\frac{\partial U_1}{\partial l_1} = \frac{1}{l_1} - \frac{\beta \delta (1 + \lambda)}{1 + \beta \delta} \frac{(1 + \beta \delta)}{T(2 + \lambda) - l_1(1 + \lambda)} - \frac{\beta^2 \delta^3 (1 + \lambda)}{(1 + \beta \delta)(1 + \lambda) \beta \delta (T(2 + \lambda) - l_1(1 + \lambda))}
\]

This gives the first order condition
\[
\frac{\partial U_1}{\partial l_1} = \frac{1}{l_1} - \frac{\beta \delta (1 + \lambda)}{T(2 + \lambda) - l_1(1 + \lambda)} - \frac{\beta \delta^2 (1 + \lambda)}{T(2 + \lambda) - l_1(1 + \lambda)} = 0
\]

Compiling the fractions
\[
\frac{1}{l_1} - \frac{(1 + \lambda)(\beta \delta + \beta \delta^2)}{T(2 + \lambda) - l_1(1 + \lambda)} = 0
\]

Multiplying with the denominators
\[
T(2 + \lambda) - l_1(1 + \lambda) - l_1(1 + \lambda)(\beta \delta + \beta \delta^2) = 0
\]

Solving for \(l_1\) yields P1’ optimal choice of leisure.
\[
l_1^{\text{opt}} = \frac{T(2 + \lambda)}{(1 + \lambda)(1 + \beta \delta + \beta \delta^2)} \quad (5)
\]

**P1’s exterior solution**

P1 cannot exceed his time constraint and if equation (5) is larger than \(T\), he will use all his time for leisure. P1’s overall response function is then
\[
l_1' = \min\left(\frac{T(2 + \lambda)}{(1 + \lambda)(1 + \beta \delta + \beta \delta^2)}, T\right) \quad (6)
\]

P1 will choose to play the exterior solution

*Theorem A*: P1 will choose the maximum leisure if and only if
\[
\frac{1}{\beta \delta + \beta \delta^2} - 1 \geq \lambda
\]

Since this project focuses on self-control represented by \( \beta \) we can simplify the model by assuming \( \delta = 1 \). The theorem then simplifies to

\[
\frac{1}{2(1 + \lambda)} \geq \beta \iff l^*_1 = T \text{ for } \delta = 1
\]

To prove the above claim, I begin with equation (6). P1’s decision depends solely on exogenous parameters and consequently P1 will play the corner solution if

\[
\frac{T(2 + \lambda)}{(1 + \lambda)(1 + \beta \delta + \beta \delta^2)} \geq T
\]

Multiplying with the denominator and dividing by \( T \). Note that \( \lambda \geq 0 \) and \( \beta, \delta > 0 \)

\[
(2 + \lambda) \geq (1 + \lambda)(1 + \beta \delta + \beta \delta^2)
\]

Subtracting one from the equation and partially expanding the RHS

\[
1 + \lambda \geq \beta \delta + \beta \delta^2 + \lambda(1 + \beta \delta + \beta \delta^2)
\]

Bracketing \( 1 + \lambda \) and subtracting \( \lambda \)

\[
1 \geq (\beta \delta + \beta \delta^2)(1 + \lambda)
\]

Dividing by the first bracket and subtracting one yields the general condition for P1’s corner solution which was claimed in Theorem A.

\[
\frac{1}{\beta \delta + \beta \delta^2} - 1 \geq \lambda \tag{7}
\]

Solving for \( \beta \) and setting \( \delta = 1 \) yields the second claim

\[
\frac{1}{2(1 + \lambda)} \geq \beta
\]

**3.4.4 Nash Equilibria**
Nash Equilibria

The Nash equilibrium of the form \((l_1, l_2)\), according to equations (3) and (6) is then:

\[
(l_1^*, l_2^*) = \left( \min \left( \frac{T(2 + \lambda)}{(1 + \lambda)(1 + \beta \delta + \beta \delta^2)}, T \right), \frac{T(2 + \lambda) - l_1(1 + \lambda)}{1 + \beta \delta} \right)
\]

P1 is choosing between interior and corner solution while P2 is always reacting according to his response function.

3.5 Effects of Withholding Solutions

3.5.1 Student Utility

The period zero value function can be used to measure the student’s overall utility.

\[
V_0 = \ln(l_1^*) + \delta \ln(l_2^*) + \delta^2 \ln\left(E(l_1^*, l_2^*)\right)
\]  

(8)

Note that the leisure values marked with only an asterisk stand for reaction functions and not just the interior parts from equations (13) and (6) respectively.

Recall that \(\tilde{\lambda}\) is such that for \(\lambda < \tilde{\lambda}\), the second period’s self will always choose the interior solution.

Theroem B: For \(\lambda < \tilde{\lambda}\), welfare is declining in \(\lambda\). Specifically, with an interior solution

\[
\frac{\partial V_0}{\partial \lambda} \bigg|_{\text{int}} = (1 + \delta + \delta^2) \frac{1}{2 + \lambda} - (1 + \delta^2) \frac{1}{1 + \lambda} \leq 0
\]

While with the corner solution \(l_1 = T\)

\[
\frac{\partial V_0^{\text{P1ext}}(T, l_2^*)}{\partial \lambda} = -\frac{\delta^2}{1 + \lambda} < 0
\]

Proof for the case of Interior Solution

In the case of P1 choosing the interior solution, \(l_1^*\) is reduced to the interior solutions \(l_1^*_{\text{int}}\). It is then possible to compute P2’s optimal leisure choice as a function of the exogenous parameters,
as \( l_2' \) describes the reaction of P2 to P1’s choice of \( l_1 \). \( l_1^{* \text{int}} \) is already a function of only exogenous parameters and has no need for further computation.

\[
l_2' (l_1^{* \text{int}}) = l_2' (\beta, \delta, \lambda)
\]

Substituting equation (5) into equation (13) to get

\[
l_2' \text{int}(\beta, \delta, \lambda) = \frac{T(2 + \lambda) - \frac{T(2 + \lambda)}{(1 + \lambda)(1 + \beta\delta + \beta\delta^2)}(1 + \lambda)}{1 + \beta\delta}
\]

Cancelling \((1 + \lambda)\) and expanding

\[
l_2' \text{int}(\beta, \delta, \lambda) = \frac{T(2 + \lambda)(1 + \beta\delta + \beta\delta^2) - T(2 + \lambda)}{(1 + \beta\delta + \beta\delta^2)(1 + \beta\delta)}
\]

Eliminating \(T(2 + \lambda)\) yields a sufficiently simplified term

\[
l_2' \text{int}(\beta, \delta, \lambda) = \frac{T(2 + \lambda)(\beta\delta + \beta\delta^2)}{(1 + \beta\delta + \beta\delta^2)(1 + \beta\delta)}
\] (9)

For the exam performance \( E(l_1, l_2) \) this implies

\[
E(l_1^{*}, l_2' \text{int} (\beta, \delta, \lambda)) = T - \frac{T(2 + \lambda)}{(1 + \lambda)(1 + \beta\delta + \beta\delta^2)} + \frac{T - \frac{T(2 + \lambda)(\beta\delta + \beta\delta^2)}{(1 + \beta\delta)(1 + \beta\delta + \beta\delta^2)}}{1 + \lambda}
\]

Before substituting \( E \) back into the value function, the term requires simplification. Expanding both \( T \) with the respective denominator yields

\[
\frac{T(1 + \lambda)(1 + \beta\delta + \beta\delta^2) - T(2 + \lambda)}{(1 + \lambda)(1 + \beta\delta + \beta\delta^2)} + \frac{T(1 + \beta\delta)(1 + \beta\delta + \beta\delta^2) - T(2 + \lambda)(\beta\delta + \beta\delta^2)}{(1 + \beta\delta)(1 + \beta\delta + \beta\delta^2)(1 + \lambda)}
\]

Partially expanding the second fraction’s numerator while simplifying the first one’s gives

\[
\frac{T((1 + \lambda)(\beta\delta + \beta\delta^2) - 1)}{(1 + \lambda)(1 + \beta\delta + \beta\delta^2)} + \frac{T(1 + \beta\delta + \beta\delta^2 + \beta\delta + \beta^2\delta^2 + \beta^2\delta^3 - 2\beta\delta - 2\beta\delta^2 - \lambda\beta\delta - \lambda\beta\delta^2)}{(1 + \beta\delta)(1 + \beta\delta + \beta\delta^2)(1 + \lambda)}
\]

Eliminating terms
\[
\frac{T((1 + \lambda)(\beta \delta + \beta \delta^2) - 1)}{(1 + \lambda)(1 + \beta \delta + \beta \delta^2)} + \frac{T(1 + \beta^2 \delta^2 + \beta^2 \delta^3 - \beta \delta^2 - \lambda \beta \delta - \lambda \beta \delta^2)}{(1 + \beta \delta)(1 + \beta \delta + \beta \delta^2)(1 + \lambda)}
\]

Putting all terms on the same denominator after cancelling out terms in the second term:

\[
T \frac{(1 + \lambda)(\beta \delta + \beta \delta^2) - 1)(1 + \beta \delta) + (1 + \beta^2 \delta^2 + \beta^2 \delta^3 - \beta \delta^2 - \lambda \beta \delta - \lambda \beta \delta^2)}{(1 + \beta \delta)(1 + \beta \delta + \beta \delta^2)(1 + \lambda)}
\]

Expanding and bracketing terms yields

\[
T \frac{(1 + \lambda)(\beta \delta + \beta \delta^2) + (1 + \lambda)(\beta^2 \delta^2 + \beta^2 \delta^3) + \beta^2 \delta^2 + \beta^2 \delta^3 - (1 + \lambda)(\beta \delta + \beta \delta^2))}{(1 + \beta \delta)(1 + \beta \delta + \beta \delta^2)(1 + \lambda)}
\]

Elimination and further bracketing

\[
E(l_1^*, l_2^*, (\beta, \delta, \lambda)) = T \frac{(2 + \lambda)(\beta^2 \delta^2 + \beta^2 \delta^3)}{(1 + \beta \delta)(1 + \beta \delta + \beta \delta^2)(1 + \lambda)}
\]

For visibilities sake, let \( \theta \) be defined as

\[
\theta = (1 + \beta \delta + \beta \delta^2)
\]

Substitution of the equations (5), (9) and (10) into (8) gives the final value function for P1 and P2 playing interior solutions.

\[
V_{0 \text{ int}} = \ln \left( T \frac{(2 + \lambda)}{(1 + \lambda)\theta} \right) + \delta \ln \left( T \frac{(2 + \lambda)(\beta \delta + \beta \delta^2)}{(1 + \beta \delta)\theta} \right) + \delta^2 \ln \left( T \frac{(2 + \lambda)(\beta^2 \delta^2 + \beta^2 \delta^3)}{(1 + \beta \delta)\theta(1 + \lambda)} \right)
\]

At this point, \( T \) is visibly only a scaling factor and can therefore be chosen arbitrarily. Defining \( T = 1 \) and using the logarithm product rule

\[
V_{0 \text{ int}} = \ln \left( \frac{2 + \lambda}{1 + \lambda} \right) + \ln \left( \frac{1}{\theta} \right) + \delta \left( \ln(2 + \lambda) + \ln \left( \frac{(\beta \delta + \beta \delta^2)}{\theta(1 + \beta \delta)} \right) \right) + \delta^2 \left( \ln \left( \frac{2 + \lambda}{1 + \lambda} \right) + \ln \left( \frac{(\beta^2 \delta^2 + \beta^2 \delta^3)}{\theta(1 + \beta \delta)} \right) \right)
\]

Bracketing after application of the logarithm quotient rule yields
\[ V_{0\text{ int}} = (1 + \delta^2)(\ln(2 + \lambda) - \ln(1 + \lambda)) + \ln\left(\frac{1}{\theta}\right) + \delta \left(\ln(2 + \lambda) + \ln\left(\frac{(\beta \delta + \beta \delta^2)}{(1 + \delta)\theta}\right)\right) + \delta^2 \left(\ln\left(\frac{(\beta^2 \delta^2 + \beta^2 \delta^3)}{(1 + \beta \delta)\theta}\right)\right) \]

Taking the derivative with respect to \( \lambda \)

\[ \frac{\partial V_{0\text{ int}}}{\partial \lambda} = (1 + \delta^2) \left[ \frac{1}{2 + \lambda} - \frac{1}{1 + \lambda} \right] + \delta \frac{1}{2 + \lambda} \]

Rearranging the terms yields the originally claimed equation

\[ \frac{\partial V_{0\text{ int}}}{\partial \lambda} = (1 + \delta + \delta^2) \frac{1}{2 + \lambda} - (1 + \delta^2) \frac{1}{1 + \lambda} \]

The derivative is negative if

\[(1 + \delta + \delta^2) \frac{1}{2 + \lambda} < (1 + \delta^2) \frac{1}{1 + \lambda}\]

Multiplying with the denominators

\[(1 + \delta + \delta^2)(1 + \lambda) < (1 + \delta^2)(2 + \lambda)\]

Solving for \( \lambda \), we see that the derivative is negative for

\[ \lambda < \frac{1 + \delta^2 - \delta}{\delta} \quad (12) \]

Plotting the RHS of (12) reveals its smallest value is at \( \delta = 1 \) (see Figure 1). It furthermore shows that for smaller \( \delta \), the derivative is still negative even for values of \( \lambda > 1 \). For all values fulfilling the above equation however, the derivative is negative. Given that in this chapter \( \lambda \leq 0.7 \) is assumed, the claim can be made that an increase in \( \lambda \) has a negative effect on the welfare of a student as long as P1 chooses to play the interior solution.
Figure 1: RHS of inequality (12). X Axis depicts $\delta$, Y Axis depicts $\lambda$. All points below the graph fulfill the inequality.

**Proof for the case of a Corner Solution in period 1**

Equation (3) shows the response function of P2. P1 choosing $l_1 = T$ is a special case:

$$l_2^*(l_1 = T) = \frac{T(2 + \lambda) - T(1 + \lambda)}{1 + \beta \delta} = \frac{T}{1 + \beta \delta}$$

Note that the decision is independent of $\lambda$. The exam performance $E$ is consequently

$$E(l_1, l_2) = E(T, l_2^*(l_1 = T)) = \left(\frac{T - \frac{T}{1 + \beta \delta}}{1 + \lambda}\right) \frac{T}{1 + \lambda} \frac{\beta \delta}{(1 + \beta \delta)(1 + \lambda)}$$

The value function is then

$$V_0^{P1_{ext}} = \ln(T) + \delta \ln\left(\frac{T}{1 + \beta \delta}\right) + \delta^2 \ln\left(T \frac{\beta \delta}{(1 + \beta \delta)(1 + \lambda)}\right)$$

Using the logarithm quotient and product rules yields

$$V_0^{P1_{ext}} = \ln(T) + \delta \ln\left(\frac{T}{1 + \beta \delta}\right) + \delta^2 \left(\ln\left(\frac{\beta \delta}{1 + \beta \delta}\right) - \ln(1 + \lambda)\right)$$
The derivative with respect to $\lambda$ is

$$\frac{\partial V_0^{P_{1ext}}(T, l_2^*)}{\partial \lambda} = -\frac{\delta^2}{1 + \lambda} < 0$$

The leisure decision is not affected by $\lambda$. The effect of an increase in $\lambda$ on the value function is strictly negative. The effect does not depend on $\beta$. Due to the logarithm being a monotonic transformation, the sign of the derivative of $\ln(G)$ must be the same as the derivative of $G$. The left inequality of the following has been proven above, implying that an increase in $\lambda$ has a negative effect on the exam performance.

$$\frac{\partial \ln(E)}{\partial \lambda} < 0 \iff \frac{\partial E}{\partial \lambda} < 0$$

### 3.5.2 Exam Performance

*Theorem C: An increase in $\lambda$ has a negative effect on the exam performance $E$*

For the interior case, equation (10) states $E(l_1^*, l_2^*_{int})$. Taking the logarithm on both sides yields

$$\ln\left(E(l_1^*, l_2^*_{int}(\beta, \delta, \lambda))\right) = \ln\left(T \frac{(2 + \lambda)(\beta^2 \delta^2 + \beta^2 \delta^3)}{(1 + \beta \delta)\theta(1 + \lambda)}\right)$$

Applying logarithmic rules

$$\ln\left(T \frac{(2 + \lambda)(\beta^2 \delta^2 + \beta^2 \delta^3)}{(1 + \beta \delta)\theta(1 + \lambda)}\right) = \ln(2 + \lambda) - \ln(1 + \lambda) + \ln(\beta^2 \delta^2 + \beta^2 \delta^3) - \ln((1 + \beta \delta)\theta)$$

The derivative with respect to $\lambda$ is analogous to section 3.4.1:

$$\frac{\partial \ln(E)}{\partial \lambda} = \frac{1}{2 + \lambda} - \frac{1}{1 + \lambda} < 0$$

Due to logarithm properties, the effect of $\lambda$ on the exam performance is negative for $P_1$ and $P_2$ playing their respective interior solutions. For proof of the theorem in the corner solution see the previous section.

### 3.5.3 From Case to Case
In the previous sections I have shown that an increase in $\lambda$ cannot increase student welfare or exam performance, given that P1 chooses to play either his interior or corner solution. This choice is however affected by $\lambda$, yet the effect stays negative. The selection into the case depends solely on whether inequality (7) holds. Let $\bar{\lambda}$ be that $\lambda$ for which the inequality is filled with equality, thus

$$\bar{\lambda} = \frac{1}{\beta \delta + \beta \delta^2} - 1$$

Figure 2 displays the leisure values of a student with a very strong self-control problem for increasing values of $\lambda$. Figure 3 showcases the exam performance and the period zero utility of the same student. $\bar{\lambda}$ values at around 0.17 and is represented by the vertical line in both figures. For $\lambda \leq \bar{\lambda}$, P1 will play $l_1 = T$. With increasing $\lambda$, time allocation, utility and exam performance stay constant for $\lambda \leq \bar{\lambda}$. An increase up to $\lambda > \bar{\lambda}$ again decreases period zero utility and exam performance, although at a more graduate slope. It can be seen that utility, exam performance and leisure all have a kink at $\lambda = \bar{\lambda}$, yet there are no jumps. As the effect of an increase in $\lambda$ on utility and exam performance is negative on both sides of $\bar{\lambda}$, the transition from corner to interior solution also has a negative effect on period zero utility and exam performance.

![Corner Solution: Leisure](image)

Figure 2: Leisure values for different values of $\lambda$. $\beta = 0.45; \delta = 1$
3.5.4 Total Study Time

The total time spent on studying by the student is worth examination as there is a significant difference depending on the student’s level of self-control. Students with perfect self-control will not increase their total study time with an increase in $\lambda$, while students with imperfect control increase their total study time. I will examine the effect of $\lambda$ on the total study time.

*Theorem D:* For the interior solution, total study time $S$ is at a global maximum at $\hat{\lambda}$ with

$$\hat{\lambda} = \frac{1 + \beta \delta}{\sqrt{\beta \delta (1 + \delta)}} - 1$$

$$\hat{\lambda} = 0, \quad \text{for } \beta \land \delta = 1$$

$$\hat{\lambda} > 0, \quad \text{for } \beta \lor \delta < 1$$

*Proof:* Equation (9) states P2’s leisure choice depending only on exogenous parameters for P1 choosing an interior solution.
\[ l_2 = l_2^* \text{int}(\beta, \delta, \lambda) = \frac{T(2 + \lambda)(\beta \delta + \beta \delta^2)}{(1 + \beta \delta + \beta \delta^2)(1 + \beta \delta)} \]

Equation (5) states P1’s choice of leisure for sufficiently large values of \( \beta \) and \( \delta \); equation (7) is assumed not to hold. P1 therefore chooses his leisure

\[ l_1 = l_1^* \text{int} = \frac{T(2 + \lambda)}{(1 + \lambda)(1 + \beta \delta + \beta \delta^2)} \]

The total time spent studying \( S(l_1, l_2) \) is:

\[ S(l_1, l_2) = T - l_1^* \text{int} + T - l_2^* \text{int} \]

Inserting for \( l_1^* \text{int} \) and \( l_2^* \text{int} \) and bracketing \( T \)

\[ S(l_1, l_2) = T \left( 2 - \frac{(2 + \lambda)}{(1 + \lambda)(1 + \beta \delta + \beta \delta^2)} - \frac{(2 + \lambda)(\beta \delta + \beta \delta^2)}{(1 + \beta \delta + \beta \delta^2)(1 + \beta \delta)} \right) \]

As \( T \) is an arbitrary scaling factor it can be set equal to 1. Using (11) and applying a new definition for the sake of visibility gives

\[ \alpha = (\beta \delta + \beta \delta^2) \]

\[ S(l_1, l_2) = 2 - \frac{(2 + \lambda)}{(1 + \lambda)\theta} - \frac{(2 + \lambda)\alpha}{\theta(1 + \beta \delta)} \]

The derivative w.r.t. \( \lambda \) then is

\[ \frac{\partial S}{\partial \lambda} = + \frac{1}{(1 + \lambda)^2 \theta} - \frac{\alpha}{(1 + \beta \delta)\theta} \]

The effect of an increase in \( \lambda \) on first period study time is positive, yet decreasing, whereas the effect on the study time in the second period is negative and constant.

\( S \) can easily be shown to be concave in \( \lambda \)

\[ \frac{\partial S}{\partial \lambda} = + \frac{1}{(1 + \lambda)^2 \theta} = \frac{1}{(1 + \lambda)}(1 + \lambda)^{-2}\theta^{-1} \]

\[ \frac{\partial S}{\partial \lambda} = - \frac{2}{(1 + \lambda)^{\lambda}\theta} \]
Consequently, the stationary point must be maxima. The total study time then has a maximum at the root of the first order derivative

$$\frac{\partial S}{\partial \lambda} = \frac{1}{(1 + \lambda)^2 \theta} - \frac{\alpha}{(1 + \beta \delta) \theta} = 0$$

Multiplication with $\theta$ and then with the resulting denominators yields

$$1 + \beta \delta = \alpha (1 + \lambda)^2$$

Simplification grants the quadratic equation

$$\lambda^2 + 2\lambda + 1 - \frac{(1 + \beta \delta)}{\alpha} = 0$$

Solving for $\lambda$ leads to

$$\lambda = \pm \sqrt{\frac{1 + \beta \delta}{\alpha}} - 1$$

Substituting $\alpha$ gives the two solution candidates

$$\lambda = \pm \sqrt{\frac{1 + \beta \delta}{\beta \delta (1 + \delta)}} - 1$$

As $\lambda$ is defined as non-negative, the negative result is not relevant. The stationary point of total study time is therefore at:

$$\hat{\lambda} = \sqrt{\frac{1 + \beta \delta}{\beta \delta (1 + \delta)}} - 1$$

For $\delta = 1$ this is

$$\hat{\lambda} = \sqrt{\frac{1 + \beta}{2\beta}} - 1$$

$$\hat{\lambda} = \sqrt{\frac{1 + \delta}{\delta (1 + \delta)}} - 1 =$$
As \( \hat{\lambda} \) is increasing in both \( \delta \) and \( \beta \), the initial claim is proven.

\[
\begin{align*}
For \beta \land \delta = 1, & \quad \hat{\lambda} = 0 \\
For \beta \lor \delta < 1, & \quad \hat{\lambda} > 0
\end{align*}
\]

**Corner Solution**

In the exterior solution, \( \lambda \) has no effect on the leisure choice and therefore no effect on total study time.

P1 choosing to play \( l_1 = T \) is a special case of equation (3).

\[
l_2 = \frac{T((2 + \lambda) - (1 + \lambda))}{1 + \beta \delta}
\]

The resulting study time is consequently:

\[
S = 2T - l_1 - l_2 = 2T - T - \frac{T((2 + \lambda) - (1 + \lambda))}{1 + \beta \delta}
\]

This can be simplified to:

\[
S = T - \frac{T}{1 + \beta \delta}
\]

The value of \( \lambda \) has no effect on the amount of study time for P1 choosing the exterior solution.
4 Simulation Results

4.1 Attendance

The question at the beginning of the chapter is: What is the effect of not uploaded solutions on student welfare, exam performance and seminar attendance. This chapter will showcase the results of simulating the mathematical equations derived in chapter 3.

Looking at Figure 4, it can be seen that a student with neither temporal preference ($\delta = 1$) or self-control problems ($\beta = 1$) has a perfectly smooth time allocation under $\lambda = 0$. His study time in periods one and two is the exact same if solutions are available. For increasing values of $\lambda$, thus lack of solutions, the student transfers study time to the first period as the productivity in the second period drops. This represents the student spending more time in the seminar while spending less time studying in the library right before the exams. The total time spent studying decreases with lower period two productivity as proven in Theorem D. The student is now substituting more costly exam performance for additional leisure while shifting his production to the more productive period. As total study time and productivity are both decreasing, exam performance must be decreasing. Similarly, as leisure allocation becomes more unequal among periods, student welfare must also decrease.

Figure 5 shows the attendance values of a student with some, but rather weak, self-control. Students with lack of self-control generally study relatively more in period two and less in period one compared to the rational student. The lower $\beta$, the stronger the tendency towards studying in period two. This is consistent with expectations- a student with lack of self-control procrastinates studying towards the end of the semester.

The student in Figure 5 is not studying in the first period if solutions are available. As solutions are becoming less available, thus under increasing values of $\lambda$, he shifts study time from the less productive second period. In other words, the student spends less time studying at the end of the semester and attends more and more of the seminar. Different from the self-controlled student, total study time is increasing for small values of $\lambda$ and only decreasing for bigger values of $\lambda$. This implies that the student substitutes an hour in the library with more than one hour of seminar attendance as long as the penalty of lacking solutions is not too grave. Note, however, that the
student does most of his studies in period two which becomes less and less effective as $\lambda$ increases. The effects on exam performance and welfare can therefore not be determined from this graph.

**Figure 4:** Time allocation of perfectly rational student: $\beta = 1; \delta = 1$

**Figure 5:** Time allocation of a student with self-control problem: $\beta = 0.5; \delta = 1$
The time allocation of a student with even less self-control is shown in Figure 6. Students with extreme self-control problems do not study in period one at all, even if the productivity in period two is diminished. For small values of $\lambda$ the time allocation does not change. P1’s regard for the future and exam performance is so low that even with falling productivity of study time in the second period, he does not study. The only effect of $\lambda$ is of the first order- it decreases the productivity of the time spent studying in period two. With higher values of $\lambda$, the student follows the same pattern as the other students with weaker self-control problems. Theorem A describes the value combinations of $\beta$ and $\delta$ that lead to this type of behavior.

**Figure 6: Highly troubled student’s time allocation with $\beta = 0.45; \delta = 1$**

The three above figures show that for both students with and without self-control problems, study time in period two is decreasing linearly in $\lambda$, whereas period one study time’s decline is lessening with increasing $\lambda$. The result is consistent with equations (5) and (9).
4.2 Welfare & Exam Performance

Figure 7 shows the absolute values of welfare for different students. For all types of students, welfare is strictly declining in $\lambda$. While students study in both periods, the decline in welfare is independent of the level of self-control (see Theorem B). Students with extreme lack of self-control however face a stronger decline in welfare for parameter values that fulfill Theorem A. The extremely troubled student, like the one presented in Figure 6, has no way of shifting study time away from the decreasingly productive second period. As a consequence, the student’s whole study time is affected by the lower productivity and therefore his welfare is falling steeper than the welfare of students with better self-control.

![Student Welfare](image)

**Figure 7: Student welfare as a function of the productivity penalty $\lambda$; $\delta = 1$**

Exam performance values in Figure 8 show a picture similar to welfare. Both students with and without self-control problem have declining values for increases in $\lambda$. Simulation values show that less self-control leads to a less steep decline of exam performance when $\lambda$ increases. The difference is small and is increasing with a stronger self-control problem.
Figure 9 shows exam performance as a percentage of its value at $\lambda = 0$. Its calculation is shown below. Both the perfectly rational and the self-control troubled student’s percentage exam performance curves coincide. This would be the case for all $1 < \beta < 0.5$. Values lower than that lead to a corner solution and induce a higher slope for low values of $\lambda$. It further implies that the percentage change is independent of $\beta$ as long as an interior solution takes place. This can be shown from equation (10). The very troubled student cannot shift study time to period one and therefore suffers a stronger loss of exam performance analogous to his welfare loss. This can be seen in both relative and absolute terms.

The percentage values in Figure 9 can be deducted as follows. Equation (1) states that Exam Performance $E$ is a function of leisure in both periods and $\lambda$. If leisure is chosen optimally according to the backwards induction model, exam performance can be seen as a function of the exogenous parameters.

$$E(l_1^*, l_2^*) = F(\beta, \delta, \lambda)$$

The percentage value $\hat{F}$ then is

$$\hat{F}(\beta, \delta, \lambda) = \frac{F(\beta, \delta, \lambda)}{F(\beta, \delta, 0)}$$

Figure 10 and Figure 11 show welfare decomposed into the utility received from leisure and from exam performance. Graphical analysis shows that the slopes’ signs are the same for students with and without self-control problem. Yet, the values strongly differ: while the former receives more utility from exam performance and less from utility, the latter gets more utility from leisure and less from exam performance. For the rational student, this seems normal as he substitutes from a first-best to react to the productivity change. The student with self-control problem however does the same— he increases his utility from leisure and decreases utility from exam performance.

Given the original intention behind withholding the solutions is among others to increase academic performance and fight student procrastination, it is quite ironic that both rational and self-control lacking students experience an increase in utility from leisure while receiving less utility from their academic performance.
Figure 8: Absolute values of Exam Performance. $\delta = 1$

Figure 9: Exam Performance as percentage of its value at $\lambda = 0$, thus $\hat{E}(\beta, \delta, \lambda)$. Beta = 0.5 and Beta = 1 are overlapping perfectly.
Figure 10: Utilities derived from exam performance and leisure for a perfectly rational student. $\beta = 1; \delta = 1$

Figure 11: Utilities derived from exam performance and leisure for a student with self-control issues. $\beta = 0.5; \delta = 1$
The combined effect of the shift of study time and the decrease in productivity leads to decreasing average productivity for small values of $\lambda$ and increases again for higher values of $\lambda$. Average productivity $A$ is defined as period productivity times its share of total study time and can be seen in Figure 12.

$$A = A(l_1, l_2) = \frac{(T - l_1)}{(T - l_1) + (T - l_2)} + \frac{(T - l_2)}{(T - l_1) + (T - l_2)} \frac{1}{1 + \lambda}$$

It can further be observed that the productivity minimum is reached at lower values of $\lambda$ for weaker self-control problems. The minimum can be explained through the time-shifting behavior of the student. For small values of $\lambda$ the decrease in average productivity is high as large parts of total study time are affected by diminished productivity. With increasing values of $\lambda$ however, the share affected becomes smaller. In addition, the bigger $\lambda$, the bigger the gain in average productivity from shifting time towards period one.

![Figure 12: Average productivity for different levels of lack of self-control. $\delta = 1$](#)
5 Large Penalty Values

5.1 Introduction

In the analysis above, $\lambda$ is assumed to be smaller than 0.7 which ensures an interior solution for leisure in period two. This assumption will be relaxed in this chapter which allows for larger values of $\lambda$. This opens up for the possibility of P2 choosing to use all his time on leisure which introduces a jump in P1’s overall utility function. A large enough penalty on period two productivity leads to a solution in which P2 does not study and P1 does all the studying. As this is then not affected by the lack of solutions, the student reaches welfare similar to $\lambda = 0$.

There are several reasons why this was delayed to the end. First of all, the values that are at question imply a decrease in productivity by more than 50%, thus a student needs to spend another half hour per hour studied to achieve the same result as if he had had access to the solutions. That is already a fairly high productivity penalty. However, given that the evidence for the value of this parameter is purely anecdotal, the results of this thesis should be confirmed also for higher values.

Another reason is that the corner solution to the model includes a non-concave utility function with a jump which makes the analysis and interpretation rather difficult. The determination has to rely on simulation to find the effects. Furthermore, the result is not very relevant to the question at hand. It implies that the productivity in the library is so low that the student finishes all his studying before the seminar period ends and takes all the remaining leisure in the exam preparation period. This scenario appears to be a bad description of the time allocation of real students. Even if the case is plausible in the model, the productivity penalty through withheld solutions would need to be very high to achieve this behavior with real students. The case can therefore be handled with low priority.

5.2 Backwards induction

The response function of P2 is different from equation (3). The added minimum operator describes the fact that if P1 studies a lot, the time constraint will bind and $l_2 = T$ will be played. P2’s actual response function then is:
\[ l_2^* = \min \left( \frac{T(2 + \lambda) - l_1(1 + \lambda)}{1 + \beta \delta}, T \right) \]  \tag{13}

This implies that P2 studies a positive amount of time and plays the interior solution according to equation (3), or plays \( l_2 = T \) for sufficiently small values of \( l_1 \).

As it is difficult to substitute a minimum operator, a case distinction must be done. As the case that P2 plays an interior solution has already been analyzed, the following will take the consideration that P2 plays \( l_2 = T \). The maximization problem of P1 then is the following:

\[
\max_{l_1} U_1 = \ln(l_1) + \beta \delta \ln(T) + \beta \delta^2 \ln(T - l_1) \]  \tag{14}

Note that the maximization is not strategic anymore, as P2’s behavior is set. The first order condition is

\[
\frac{\partial U_1}{\partial l_1} = \frac{1}{l_1} - \frac{\beta \delta^2}{T - l_1} = 0
\]

Multiplying with the denominators yields

\[ T - l_1 - \beta \delta^2 l_1 = 0 \]

Solving for \( l_1 \) gives the optimal leisure choice

\[ l_1^c = \frac{T}{1 + \beta \delta^2} \]  \tag{15}

As this value is always smaller than \( T \), there is no need to check if the constraint has been fulfilled. This equation states the optimal response of P1 for the belief that P2 will play a corner solution.

**Non-concavity**

P1 is facing two different scenarios: one in which P2 plays an interior solution and one in which he uses all his time for leisure. However, which scenario will play out solely depends on P1’s choice of leisure. The two choices manifest in two different maximization problems and utility
functions of which P1 will always choose the one that grants him higher utility. The functions are found in (4) and (14).

P1 chooses the leisure value which will make P2 play the solution which will grant him the highest utility. P1’s behavior can be described with

\[ U_1(l_1, l_2) = U_1(l_1, l_2(l_1)) \]

With \( l_{1C}^* \) being the optimal response to P2 playing a corner solution and \( l_1^* \) being the optimal response for the other two cases according to equation (6), the optimal decision of P1 is:

\[
l_1 = \begin{cases} 
  l_1^* \text{ if } U_1(l_1^*, l_2(l_1^*)) \geq U_1(l_{1C}^*, T) \\
  l_{1C}^* \text{ if } U_1(l_1^*, l_2(l_1^*)) < U_1(l_{1C}^*, T) 
\end{cases}
\]

Figure 13 shows the two possible utility results of P1 for inserted parameter values depending on his leisure choice. The resulting target function is then the set containing all points that are weakly bigger than their counterpart at the same leisure-value. It can have zero, one or two stationary points inside the relevant domain \( l_1 \leq T \). In the portrayed case there are two stationary points, and a kink at \( l_1 \approx 0.78 \). For the depicted set of parameters, P1 chooses to act according to (15), plays the corner solution and lets P2 use all his time for leisure. For different parameters, especially smaller \( \lambda \)-values, P1 will play the interior solution according to (5). This implies that the stapled function has the highest point within the domain. The other corner solution in which P1 spends all his time on leisure would manifest in this figure with the stapled function having a maximum outside the domain, thus \( l_1 > T \).

Another case is that for certain set of parameters, two maxima will have the exact same utility value, making P1 indifferent between them. For lower \( \lambda \), he would choose the interior, for higher \( \lambda \) he would choose the exterior. This causes a jump for a certain increase in \( \lambda \). The simulation shows that at the point of the jump from interior to corner solution, the same values of welfare and exam performance as observed under \( \lambda = 0 \) can be reached in the case of \( \beta = 0.5; \delta = 1 \). For other cases of the corner solution the effect is weaker, yet the student still comes close to the total study time he achieved under \( \lambda = 0 \). As the study time is now entirely not affected by \( \lambda \), the average productivity is at maximum and the positive effect is therefore quite strong.
Figure 13: P1 Utility functions; Y-Axis depicts P1’s total utility, X-Axis depicts $l_1$; $\beta = 0.5, \delta = 1; T, \lambda = 1$. P1 chooses to do all the studying in this case.

Nash Equilibria

The Nash equilibrium of the form $(l_1, l_2)$, according to equations (13), (5) and (15), is then

$$\begin{cases} l_1^* \text{ if } U_1(l_1^*, l_2(l_1^*)) \geq U_1(l_1^c, T) \\ l_1^c \text{ if } U_1(l_1^*, l_2(l_1^*)) < U_1(l_1^c, T) \end{cases}, l_2^*$$

P2 will always respond with $l_2^*$ as that is optimal for all values of $l_1$. P1 will choose to play $l_1^*$ or $l_1^c$ depending on which gives him the higher utility. Which of these will be realized depends on the parameters.

5.3 Effect on Welfare and Exam Performance

In the case that it is optimal for P1 to play $l_1^c$, P2 will react with $l_2 = T$. The value function in period zero is then:

$$V_0^{P2ext} = \ln(l_1^c) + \delta \ln(T) + \delta^2 \ln(E(l_1^c, T))$$  \hspace{1cm} (17)

With the exam performance $E$ taking the form of
\[
E(l_{1c}, T) = T - \frac{T}{1 + \beta \delta^2} + \frac{T - T}{1 + \lambda}
\]  

(18)

This simplifies to

\[
V_0^{P2ext} = \ln\left(\frac{T}{1 + \beta \delta^2}\right) + \delta \ln(T) + \delta^2 \ln\left(\frac{T(\beta \delta^2)}{1 + \beta \delta^2}\right)
\]

The derivative with respect to \(\lambda\) then is:

\[
\frac{\partial V_0^{P2ext}}{\partial \lambda} = 0
\]

\(\lambda\) has no effect on either the value function or the leisure decision. It can therefore not have a positive effect on either the exam performance, which is a direct function of the leisure choice, or the overall utility itself. Note that the important effect of this corner solution takes place in the transition from the interior solution to the corner solution.

### 5.4 Interpretation

The student that plays the corner solution has perfect attendance and can recover large parts of the welfare and exam performance lost due to the reduced productivity as he completely avoids the penalty. He has the highest seminar attendance of all student types observed in the model.

The result has to be taken with a grain of salt however. It only occur for values of \(\lambda\) above 0.7 which implies that a student has to spend seven minutes more for every ten minutes he studies to make up for the lack of solutions. Given the justification of the parameter, this value seems to be quite high. Furthermore, the scenario that is played out represents a student who is so strongly influenced by the lack of solutions that he completes all preparation in the beginning of the semester and takes leisure later. A student that is capable of this does not qualify to the target group of a seminar leader who is trying to improve seminar attendance and fight procrastination.
6 Conclusions

This project set out to answer the question if withholding the solutions from students could increase student welfare or exam performance by counteracting their procrastinating behavior. To answer the question a student with quasi hyperbolic discounting is modelled in a two-period model. He faces a tradeoff between leisure and exam performance. The lack of solutions is implemented as a flat penalty to study productivity in the second period. The behavior of the student for different penalty values is then calculated and simulated.

The first period represents the seminar attendance and the second period represents the preparation time before the exam. The exam is often similar to the exercises given in the seminar. This is relevant for the interpretation of the penalty on period two productivity. Even perfectly rational students do not have perfect attendance or perfect notes due to various reasons as stated in chapter 3.3. The students then need to gather knowledge via other, less time-efficient methods. This implies that productivity in the second period is reduced by a certain amount, no matter how rational the student is.

The penalty imposed on all students alike is a flat multiplier. This is a simplification of the real world. In real universities, the penalty on productivity decreases with seminar attendance instead of being flat, which would create additional incentive to attend. Modelling the productivity as a dependent variable however results in a strong complication of the model. It can also be argued that there are exogenous reasons that bar the student from having perfect attendance. In that case, the flat penalty model is a decent representation of the studying time allocation process.

The model is very clear on its results for the effect of withholding solutions. Theorem B, Theorem C, and the simulation show that student welfare and exam performance are lower for increasing penalty values. The percentage effect on welfare is stronger for students with bigger self-control problems, while the percentage effect on exam performance is only affected if the student has such a strong self-control problem that he does not study at all in the first period.

While the rational student substitutes a minute of study time at the end of the semester with less than a minute of seminar attendance for all increases in the penalty values, the self-control troubled student increases his overall study time and studies more for small penalty values. Yet average productivity is decreasing for all students and the resulting impediment on welfare and exam performance outweighs the positive effect of higher study time.
The results show that withholding solutions strictly increases seminar attendance. The seminar leader might observe this and believe that higher seminar attendance brings better academic performance. This is consistent with an email exchange I had with the heads of two German economic faculties. The model, however, indicates that this belief is misguided. While the model predicts higher seminar attendance, it also predicts that more seminar attendance is associated with lower grades and more utility from leisure. With the literature on the effect of seminar attendance on academic success being ambiguous, the seminar leaders’ belief might be mistaken and harmful to students.

There are numerous imaginable reasons to withhold solutions other than the one analyzed in this project. While this project analyzes the possibility of paternalism to counteract procrastination and ease up the effect of self-control problems, some of the other reasons could be rather technical. These range from the workload in preparing solutions being significant via possible legal consequences to copyright infringement with the authors of the textbook the course is following. More complex reasons, at least in terms of economic science, are mostly related to the connection between seminar attendance and solution availability. One example is the externality of not attending- the students that did not attend will often ask the seminar teacher via email or appointment for a question he answered in the seminar. By increasing seminar attendance, the teacher could reduce this externality and save himself work.

The results of this model indicate that the lack of uploaded solutions harms students with good and bad attendance. It is however rather clear that procrastination cannot be combated by withholding the solutions- on the contrary, it hurts the troubled student even more as he cannot shift study time easily. Where the teacher sets out to help the student’s grades and welfare, he achieves that that the student has a better leisure time and performs worse at the exam.
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