On the Evaluation of Economic Theories using Machine Learning Techniques

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The *completeness* of a given parametric model, as introduced by Fudenberg et al. (2022), reveals (i) how large a fraction of the predictable variation of the data the model captures, and (ii) how large a gain in predictive performance the model achieves compared to a simple baseline model. In turn, this shows the potential gains by either considering more complex functional forms or by adding additional terms to the model. The current definition (i) assumes a data abundant environment and (ii) allows for subjective definitions of the baseline. We show how to perform the estimation in a data sparse environment and propose a standardization of the baseline to be the lowest reasonable estimate. Motivated by the estimation of mixtures of utility models (See e.g., Bruhin et al. 2010), we expand on the completeness concept to allow for unobserved heterogeneity. Using panel data from the lab containing experimental observations of binary dictator games and reciprocity games from Bruhin et al. (2019), we show how to apply these extensions.
JEL codes: C52, C53, D11, D12
Keywords: theory evaluation, machine learning, random utility, mixture models, social preferences, matrix factorization, latent factor models, recommender systems

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1. Introduction

Laboratory data on choices provide the means to test whether actual decision-making matches with proposed theories of choice. In particular, the data makes it possible for us to investigate the extent to which parameterized theories, in their proposed functional form, are able to predict individuals' choices. Such an investigation sheds light on two important points that provide insights on the vary nature of decision-making on the considered domain. Firstly, given a theory's included behavioral motives, it allows us to conclude how well the theory is able to predict choices, compared to how well a theory could have predicted on the considered domain. In turn, this allows us to conclude (i) whether the proposed functional form is optimal and (ii) how much better a theory could perform by considering more complex functional forms. Secondly, it allows us to conclude the extent to which the behavioral motives included in the model matter for decision-making. On the domain of other-regarding preferences[1], such motives might, for instance, be inequity aversion or reciprocity. These two points can be sufficiently addressed in a representative agent setting.[2] Given a proposed theory of choice that matches actual decision-making is found, a third point worth investigating relates to heterogeneity of choices. In its most general form, a proposed theory allows for individual specific parameter values. However, as with the functional form of our theories, we tend to prefer sparsity in the variation in parameter values across individuals within a specific theory. In particular, we would like to know if the heterogeneity in choices across individual can be captured in the given theory by allowing for a relatively small number of types that are economically distinguishable.

In this paper, we address these three points on the domain of other-regarding preferences. We address them by evaluating simple parameterized social preference theories using data on binary dictator games and reciprocity games from Bruhin et al. (2019). The social preference theories are designed in a way that gradually increases the complexity by sequentially adding behavioral motives. Our starting point is a linear preference model, in which the decision maker (DM) only cares about her own payoff. By sequentially adding more motives, our end point is a model that includes potentially inequity aversion (or, alternatively, differentiated altruism) and both negative and positive reciprocity.[3]

The insights mentioned above stem from the predictive performance of the models. However, merely looking at the performance of a model does not reveal the whole picture. Firstly, when we construct theories, we are likely – perhaps intentionally – not including every potential motive that may influence choice. Secondly, the act of choosing might be inherently random on its own. Thus, conditional on the included variables in the theory, we should expect some randomness in choice, leading to less than perfect predictions. It

[1] 1
[2] 2
[3] 3

follows that to evaluate the predictive capability of a given model, we need a measure that informs us on how well we could optimally predict, conditional on the included variables used in the models. Such a measure would directly show us the potential improvement, in terms of predictive performance, an alternative formulated theory could bring. Hence, this also allows for the comparison of two models, such that the improvement of including a behavioral motive becomes clear. At the same time, a lower boundary, in terms of predictive performance, is needed to inform us whether the model is able to capture the relationship between the features and choice to a sufficient degree. For instance, if the performance of a model appear relatively close to optimal, it is not clear whether it sufficiently captures structure in the data unless we compare it to a naive measure that makes predictions without feature-based information, such as the unconditional average.

In order to conduct the analysis of the two aforementioned points on the representative agent level, we first translate the social preference models into prediction rules by subsuming a random utility framework in the same manner as Bruhin et al. (2019). Subsequently, we apply the concept of a model's /completeness/ as proposed by Fudenberg et al. (2022). In our setting, a given parameterized model's completeness is calculated by the improvement in predictive capability that the model brings compared to a naive benchmark model, relative to the largest possible improvement in predictive capability in the data. The naive benchmark model in our setting is based on a simple unconditional average.[4] Such a baseline provides the best estimate when no features are used. Hence, we should expect that any proposed theory that uses information to some extent will predict at least as good. To estimate the best possible predictions, we use what is referred to as the "lookup table" algorithm in Fudenberg et al. (2022). In essence, the prediction in any given game, which is uniquely defined by its features, is the average choice within that game by the subjects. We show how to estimate this algorithm in a simple regression framework, in which we can use regularization to investigate whether we have enough data, and we compare the result to conventional machine learning (ML) algorithms, which allow for (i) a non-parametric and flexible estimation of the predictive patterns in the data to see if the aforementioned algorithm indeed is optimal in the specific setting (ii) model interpretation techniques to investigate how the features are linked to choices.

Our findings show, that a full linear model that includes all the considered other-regarding behavioral motives, achieves a relatively high completeness of approximately 82%.

We subsequently extend the setting by allowing, in each model, heterogeneity in the parameters as in Bruhin et al. (2019). That is, in each of the models we allow for the existence of a finite number of types, each characterized by their own set of parameter values. To evaluate the completeness of a model in this setting, we propose and explore two

[4] 4

extensions of the original definition of completeness. The first variant that we introduce is what we call a model's /unrestricted completeness/. Here we evaluate the predictability of a heterogeneous model by comparing its predictive performance to a fully flexible ML model that uses the subject identifier as a feature. This will provide us with an indication on how well a parametric theory consisting of a parsimonious representation of individuals, in the form of types, predicts compared to a fully flexible non-parametric model that may adjust its predictions to any of the subjects. The second variant is what we refer to as a model's /within-type completeness/. Here we evaluate the completeness of a model by estimating the completeness within each type that the given model proposes. Specifically, we compare the predictive capability within the type of a given model to that of an ML model, as the estimate of the optimal predictive performance, and to that of a simple model, as the naive benchmark. Besides allowing us to estimate the partial impact of a given behavioral motive, this will allow us to infer (i) whether there is substantial variation in a model's predictive capability across the types, and (ii) whether, for some types, a more complex social preference model is needed to fully capture the within-type behavior.

The unrestricted completeness results indicate that a linear social preference model with only three types is able to capture most of the individual variation in the data. In particular, the completeness estimates range between approximately 85% and 88%. Our within-type completeness results on this domain suggest the existence of three types in all the considered models, with two relatively large ones and one minority type. The behavior of subjects belonging to the first of the large types, which can be characterized by strong other-regarding preferences, seems to be well predicted by linear social preference models, with completeness estimates ranging between 88% and 93%. The behavior of the second-type subjects is characterized by modest other-regarding preferences. However, the linear social preference theories are only able to achieve a within-type completeness of between 60% and 65%. This indicates that a more complex theory is needed to fully capture this type's behavior. Finally, for the minority type, we find that choices are very random, in the sense that only using the subjects' own payoffs for prediction leads to relative poor predictions. However, due to the type's small size, we do not have enough power to estimate the within-type completeness.

As a final point of investigation, we increase the scope for heterogeneity by allowing for an infinite number of types in each of the social preference models. We do this by imposing assumptions on the distribution of the parameters in each of the models, allowing us to overcome the limitations due to only having a finite data sample. We once again calculate the unrestricted completeness of the models by comparing these to ML models that use the subject identifier as a feature. The results will shed light on the potential reduction in predictive capability we should expect by summarizing the population into a finite number of types as opposed to allowing for individual parameter values f_θ.

The results here show that ...

In summary, this paper expands the domain of the proposed concept of model completeness proposed by Fudenberg et al. (2022) in two important ways. Firstly, it expands its application to the domain of social preferences. Secondly, as heterogeneity is near impossible to argue against, we here show how the concept can be applied once allowing for subject heterogeneity in choices.

Roadmap. The remainder of the paper is organized as follows. The next section sheds light on related literature and distinguishes our approach. The section that follows describes the setup. In this section, the primitives of our investigation will be defined, the data that we are using will be described, and the social preference models will be presented and translated into parametric models that predict the probability of a decision maker choosing one allocation over the other. Section ? describes our estimation strategy for evaluating the completeness of the models on the aggregate level and when allowing for heterogeneity, as well as for the evaluation of within-type completeness. In Section ?, we present the findings of our investigation, first on the aggregate level, and subsequently in the heterogeneous setting. Section ? discusses our findings. Finally, Section ? concludes.

2. Generic section

This is a section. This is the section introduction. Below are the subsections. Sed ut perspiciatis, unde omnis iste natus error sit voluptatem accusantium doloremque laudantium, totam rem aperiam eaque ipsa, quae ab illo inventore veritatis et quasi architecto beatae vitae dicta sunt, explicabo.

2.1. Generic subsection

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2.2. Subsection with references

References can be appended at the end of a sentence, in parenthesis (**?**). References can also include page numbers or other bibliographical information (**?**, p. 1305). References from the same authors and same year appear as follows: (**??**). References can be in text: for instance, **?** found this and **?**, figure 1 found that. It's also possible to collate several references to the same author: for instance, **??** found things. It is also possible to cite the authors of a study by name, or the year of a study: for instance, **?** wrote a paper in **?**.

2.3. Subsection with paragraphs

Paragraph heading. Aenean fermentum purus id lacus volutpat, a eleifend mi posuere! Mauris nec nunc commodo, vehicula enim nec; vehicula ex. Nullam euismod lorem at eros efficitur: ut ultricies ante fringilla? Nam sagittis sapien id tortor commodo—a pulvinar velit ultricies... Integer ac magna vel-orci mollis vestibulum. Fusce id ipsum vel magna placerat vehicula. Curabitur ac lobortis justo.

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2.4. Subsection with an URL

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3. Section with math

This section displays a number of mathematical expressions to showcase the math fonts used in the template.

3.1. Roman letters

The Roman characters in math are just the same as the characters in the text—but in *italic*. Here are some small letters:

$$a\{p - r \times l\} + \frac{w(g/z + j)}{i(t) + j(t) + k(t) - e^{p} - x^{j}} + \frac{h[f] + x^{f}}{k[y] - e^{y} + x^{y}} = f(j)^{6+y} - i^{3}_{g,j,p} \approx (p_{ji})^{5}.$$

Here are some capital letters as well:

$$G[p + P^{7} - Q] - A_{B} + L\{j\} = F(X) \to [Y + K] \times Z_{f}/H - [g_{4} - i], \text{ for any } i.$$

The punctuation is also the same in math as in text.

3.2. Digits

The digits in math are also taken from the text font, just like the Roman characters. So 1, 2, 3, 4, 89, 03 (in text mode) is just the same as 1, 2, 3, 4, 89, 03 (in math mode). The percentage sign is also the same so 27% (in text mode) is the same as 27% (in math mode).

3.3. Greek letters

Here are some small Greek letters in a math display:

$$\alpha^{\theta} + \gamma^{4} + g(a) - \zeta \times \frac{y(\lambda)}{\kappa \cdot k + \sigma - s} \to \nu_{\eta} = \beta^{\epsilon} \cdot \delta - \mu + \frac{\xi^{4}}{\zeta_{ij}} \to m(x) + b^{e} + \omega.$$

Here are some capital Greek letters in another math display:

$$F(\Psi) - G(\Phi) \times \Delta^{10} = \Sigma \cdot \Omega^{2} - \frac{\Lambda_{i}}{\Theta_{j}} \cdot \frac{\Gamma(x)}{\Pi(t)}. \tag{1}$$

Some but not all the variants of the standard Greek letters are available. There is a variant for theta ($\vartheta \neq \theta$), for epsilon ($\varepsilon \neq \epsilon$), for pi ($\varpi \neq \pi$), and for phi ($\varphi \neq \phi$). But there

is no available variant for sigma (`varsigma` gives ς = σ), rho (`varrho` gives ϱ = ρ), and kappa (`varkappa` gives an error).

3.4. Calligraphic letters

Calligraphic letters are taken from the same family of fonts as the Greek letters. The calligraphic letters are only available for capital letters. Here are some of the calligraphic letters:

$$\frac{\mathcal{A}(A)}{\mathcal{H}} - \mathcal{B}(\beta) + \mathcal{Q}(j + 3f) \to \mathcal{Y} + \mathcal{M}(\mathcal{N} - 2) = \mathcal{J}(X) \neq \mathcal{X}(J) - \mathcal{F}[\mathcal{D} \times \Delta]^{8}.$$

3.5. Blackboard-bold letters

Here are some blackboard-bold letters, used in some mathematical expressions: $x \in \mathbb{R}^n$ but $y \in \mathbb{Q}$ and $[A_1, A_2] \in \mathbb{Z} \times \mathbb{N}$; so that $\mathbb{E}[X \mid Y] = Y + 3 \cdot \mathbb{P}(X^2) \notin \mathbb{C} \times \mathbb{1}(X \subseteq \mathbb{B})$.

3.6. Symbols

The template comes with a full set of mathematical symbols. Here is a random assortment of some symbols:

$$\left(\frac{\sum_i \vec{z}_i}{\sum_{j=-\infty}^{+\infty} X_j} \right) \pm Q \subset \mathbb{R} \neq \mathbb{C} \implies \sqrt{\frac{\mathcal{X}}{2}} > \sqrt{\mathcal{Y}} \gg \hat{b}(y_0).$$

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$$\sum_i \left[\frac{\hat{x}(i)}{\mathcal{Y}(i)} \right]^2 \leq 2\pi \Rightarrow \prod_j \bar{y}(j)^2 \geq \left\{ \iint \frac{g(h)}{\gamma(s) \times \Delta(h)} \, dh \, ds \right\} \mapsto f \circ g(x) \iff \tilde{Q}(x) \propto \frac{\dot{x}}{2}.$$

3.7. Bold characters

In the template it is possible to bold all math characters. Roman characters can be bolded, such as $\boldsymbol{a} + \boldsymbol{D} = \boldsymbol{E}^2 + \boldsymbol{j}/\boldsymbol{i}$. Greek characters can also be bolded, such as $\boldsymbol{\alpha} + \boldsymbol{\Delta} = \boldsymbol{\epsilon}^2 + \boldsymbol{\Lambda}/\boldsymbol{\Phi}$. It is also possible to bold digits: $1 + 2 \neq \mathbf{1} + \mathbf{2}$. Finally, it is possible to bold calligraphic letters: $\boldsymbol{\mathcal{C}} + \boldsymbol{\mathcal{E}} - [\boldsymbol{\mathcal{X}} + \boldsymbol{\mathcal{Y}}]$.[5]

[5] Blackboard-bold letters are already "bold" so they cannot be bolded further.

3.8. Operators

Operators in mathematical expressions are typeset with the text font. Here are a few examples:

$$\max_{x} \pi(x) = \frac{\int \ln(u) du}{\int \exp(v)\, dv} \mapsto \cos(\theta) + \sin(\omega) - \min_{z}[\tan(z)].$$

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3.9. Some equations

This subsection illustrates how the different math fonts fit together. The equations below combine various characters together.

First, here are equations in text. Lorem ipsum dolor sit amet, consectetur adipiscing elit: $\prod_i \alpha_i(X) \geq 2 \cdot [\partial a_u(Z)/\partial Z] \propto \mathcal{X} \sim 5.2\pi \rightsquigarrow +\infty$. Lorem ipsum dolor sit amet, consectetur adipiscing elit: $\sum_{x=1}^{4} \xi^{x}(j) = 0, \ \forall j \in \mathbb{R}$. Here are some other expressions: $\mathcal{R}(z) = \max\{T_1, \ldots, T_n\} > \hat{z}$, and $\mathbb{P}(T_n < z) = 1 - S(z) = F(z)$. Sed vehicula ultrices odio, vitae maximus justo convallis at. Fusce quis consequat arcu: $\alpha^* = S(z^*)$ and $S^*(z^*) = \mathbb{E}[\boldsymbol{\alpha} \mid \beta]$. Integer non ante eget purus aliquet consequat. Mauris ut dui nec ligula consectetur commodo.

Here are equations in display mode, without labels:

$$\frac{\mathcal{S}(u^*)}{1 - \frac{\partial \ln(\theta)}{\partial \theta} + [\gamma^{\eta}] - \mathcal{G}(z^*)} = \sum_{i=0}^{+\infty} \frac{dF^i(x)}{dx} - \Lambda(i) \geq \left\{ \sum_{i=0}^{+\infty} G^i - \Omega(i) \right\}$$

$$\frac{\mathbb{Q}(z^*)}{1 - \mu + \exp(\xi) \times \mathbb{M}(z^*)} = \prod_{i=0}^{+\infty} F^i - \Phi(i) \neq \left(\int_0^{+\infty} \frac{G^i}{\epsilon(i)} di \right).$$

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And here is a single equation in display mode without a label:

$$\dot{y}(t) \to \sum_{j=0}^{+\infty} \mathcal{W}^j(z^*(t)) = \frac{S(z)\mathbb{E}(N(z))}{\mu_1 - \zeta_2} \cdot 2 - \left[\prod_{i=0}^{+\infty} \mathcal{F}^i \right] - \iiint \exp(\lambda(t)\mu(s)) \sin(\theta) dt\, ds\, d\theta.$$

Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Nam consequat, ipsum eget tincidunt aliquam, mi est pellentesque lacus, nec ullamcorper leo magna a dui.

3.10. Some theorems

Here is a proposition with some more math:

PROPOSITION 1. *Lorem ipsum dolor sit amet, consectetur adipiscing elit:*

$$\sum_{k} \boldsymbol{S}_{k_x}(z) \approx \frac{S(z)^x}{k/23 - \zeta\gamma[45 - S(z)] + \ln(y) - j^2 + x(l)}. \tag{2}$$

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PROOF. Here is the proof to the proposition. Donec commodo justo a eros malesuada, eget vulputate tortor accumsan. Sed ac pulvinar nulla. Etiam quis felis dapibus, vulputate metus eu, finibus nunc. Sed vel sodales dui. Nam venenatis dolor non orci tempus fermentum. Vivamus sodales justo a ligula cursus aliquet. Sed fringilla nunc vitae justo finibus, id placerat lectus sodales. □

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LEMMA 1. *Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat:*

$$z^* = \int_0^{\infty} \alpha(i) \cdot \frac{1 - \beta}{1 - \alpha(i)\beta} \, di. \tag{3}$$

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LEMMA 2. *Consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua* $\mathcal{Z}(\alpha)$.

$$\frac{\sum_i z^i}{\prod_i q^i} \to \frac{\int_0^{\infty} \alpha(i) \cdot [1 - \beta] \, di}{1 - \exp(\alpha)\sin(\beta)}.$$

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And here is a corollary following the lemma:

COROLLARY 1. *Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua:*

$$\mathbb{E}(N(z^*)) \approx \frac{1 - \mathbb{P}(\alpha\pi)}{1 - \pi} - \frac{f(y)}{z(p)^*} + P(\Gamma).$$

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4. Section with lists

Lists are not very common in scientific papers, but they are sometimes useful. This section presents a few possible lists.

4.1. Subsection with itemized lists

Here is an itemized list with two levels:

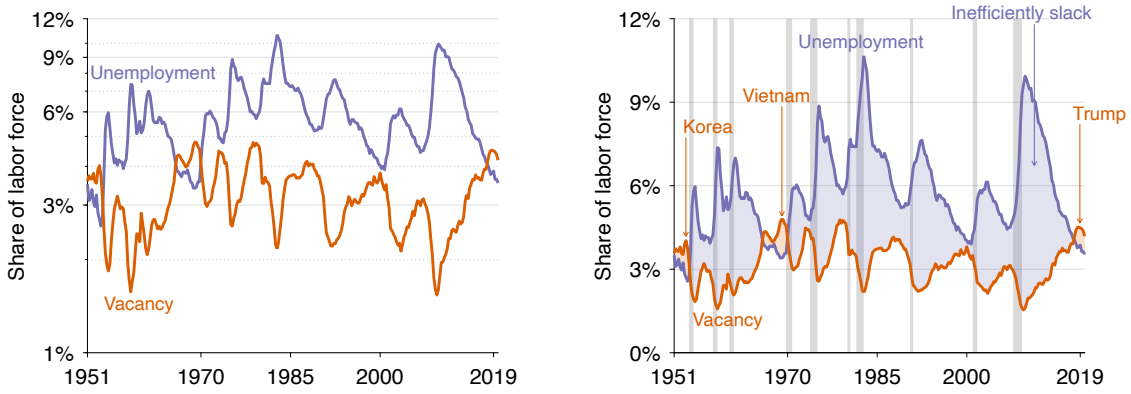
- Et harum quidem rerum facilis est et expedita distinctio.
- Nam libero tempore, cum soluta nobis est eligendi optio.
- Emporibus autem quibusdam et aut officiis debitis aut rerum necessitatibus saepe eveniet. Nam libero tempore, cum soluta nobis est eligendi optio:
  - Cumque nihil impedit
  - Quo minus id, quod maxime placeat
  - Facere possimus, omnis voluptas assumenda est
- Et harum quidem rerum facilis est et expedita distinctio.
- Nam libero tempore, cum soluta nobis est eligendi optio.

4.2. Subsection with numbered lists

And here is a numbered lists with two levels:

a. Et harum quidem rerum facilis est et expedita distinctio.
b. Nam libero tempore, cum soluta nobis est eligendi optio.
c. Emporibus autem quibusdam et aut officiis debitis aut rerum necessitatibus saepe eveniet. Nam libero tempore, cum soluta nobis est eligendi optio:
   i. Cumque nihil impedit
   ii. Quo minus id, quod maxime placeat
   iii. Facere possimus, omnis voluptas assumenda est
d. Et harum quidem rerum facilis est et expedita distinctio.
e. Nam libero tempore, cum soluta nobis est eligendi optio.

Itaque earum rerum hic tenetur a sapiente delectus, ut aut reiciendis voluptatibus maiores alias consequatur aut perferendis doloribus asperiores repellat.



A. A first panel, 1951–2019

B. A second panel, 1951–2019

FIGURE 1. Graph with two panels

This is a note for the graph. Nam libero tempore, cum soluta nobis est eligendi optio, cumque nihil impedit, quo minus id, quod maxime placeat, facere possimus.

5. Section with graphs

Here is a section with a variety of graphs. At vero eos et accusamus et iusto odio dignissimos ducimus, qui blanditiis praesentium voluptatum deleniti atque corrupti, quos dolores et quas molestias excepturi sint, obcaecati cupiditate non provident, similique sunt in culpa, qui officia deserunt mollitia animi, id est laborum et dolorum fuga.

5.1. Subsection with graphs at the top of the page

A simple two-panel graph is on figure 1. It will be placed at the top of the page, just about here. Et harum quidem rerum facilis est et expedita distinctio. Nam libero tempore, cum soluta nobis est eligendi optio, cumque nihil impedit, quo minus id, quod maxime placeat, facere possimus, omnis voluptas assumenda est, omnis dolor repellendus. Temporibus autem quibusdam et aut officiis debitis aut rerum necessitatibus saepe eveniet, ut et voluptates repudiandae sint et molestiae non recusandae.

5.2. Subsection with references to figures and panels

As usual with LaTeX, it is easy to refer to a figure: see figure 1. It is possible to refer to a specific panel in a figure, for instance figure 1A or figure 1B. Its also possible to refer to the entire figure, for instance figure 1 or figure 2. It is also possible to refer to a panel within a figure by itself, for instance panel A or panel B in figure 1.

5.3. A subsection with a full-page figure

Here is a full-page figure (figure 2). It will be placed in a full page about here.

At vero eos et accusamus et iusto odio dignissimos ducimus, qui blanditiis praesentium voluptatum deleniti atque corrupti, quos dolores et quas molestias excepturi sint, obcaecati cupiditate non provident, similique sunt in culpa, qui officia deserunt mollitia animi, id est laborum et dolorum fuga. Et harum quidem rerum facilis est et expedita distinctio. Nam libero tempore, cum soluta nobis est eligendi optio, cumque nihil impedit, quo minus id, quod maxime placeat, facere possimus, omnis voluptas assumenda est, omnis dolor repellendus. Temporibus autem quibusdam et aut officiis debitis aut rerum necessitatibus saepe eveniet, ut et voluptates repudiandae sint et molestiae non recusandae. Itaque earum rerum hic tenetur a sapiente delectus, ut aut reiciendis voluptatibus maiores alias consequatur aut perferendis doloribus asperiores repellat.

6. A section with table

Here is a section with a variety of tables. Temporibus autem quibusdam et aut officiis debitis aut rerum necessitatibus saepe eveniet, ut et voluptates repudiandae sint et molestiae non recusandae. Itaque earum rerum hic tenetur a sapiente delectus, ut aut reiciendis voluptatibus maiores alias consequatur aut perferendis doloribus asperiores repellat.

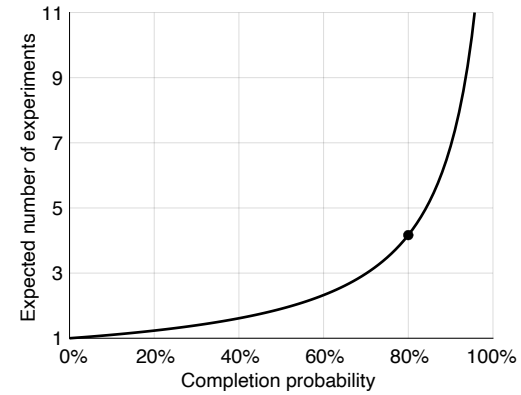
6.1. A subsection with a simple table

Table 1 is a simple table with one panel. Temporibus autem quibusdam et aut officiis debitis aut rerum necessitatibus saepe eveniet, ut et voluptates repudiandae sint et molestiae non recusandae. Itaque earum rerum hic tenetur a sapiente delectus, ut aut reiciendis voluptatibus maiores alias consequatur aut perferendis doloribus asperiores repellat. Itaque earum rerum hic tenetur a sapiente delectus, ut aut reiciendis voluptatibus maiores alias consequatur aut perferendis doloribus asperiores repellat.

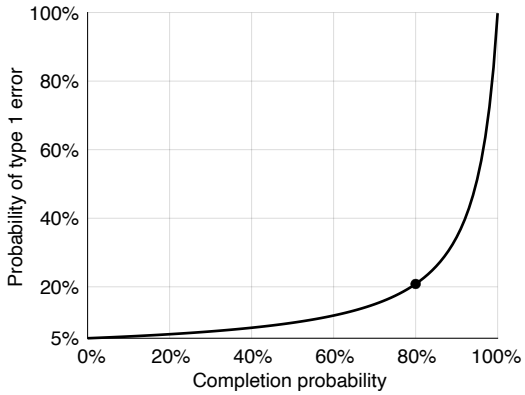
Temporibus autem quibusdam et aut officiis debitis aut rerum necessitatibus saepe eveniet, ut et voluptates repudiandae sint et molestiae non recusandae. Itaque earum rerum hic tenetur a sapiente delectus, ut aut reiciendis voluptatibus maiores alias consequatur aut perferendis doloribus asperiores repellat.

6.2. A subsection with a multi-panel table

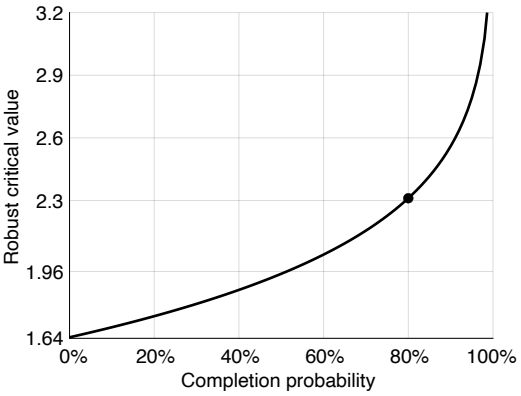
Table 2 is a more sophisticated table with several panels. Temporibus autem quibusdam et aut officiis debitis aut rerum necessitatibus saepe eveniet, ut et voluptates repudiandae sint et molestiae non recusandae. Itaque earum rerum hic tenetur a sapiente delectus, ut



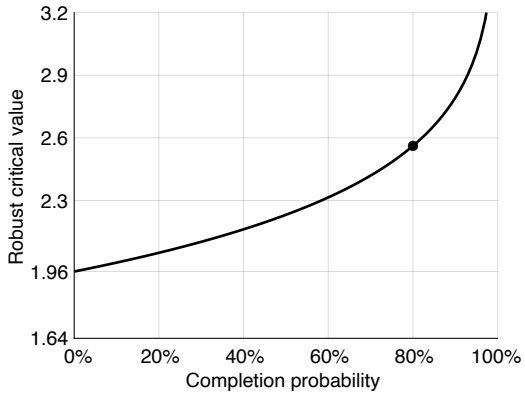
A. A first black-and-white panel



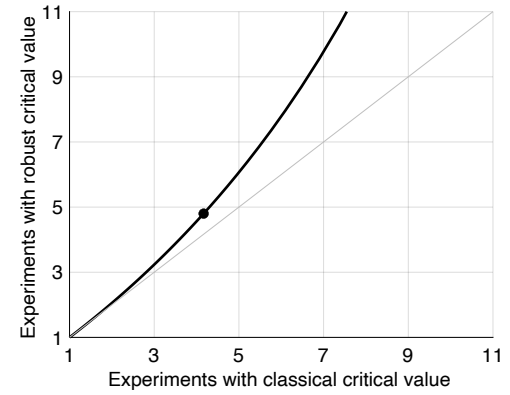
B. A second black-and-white panel



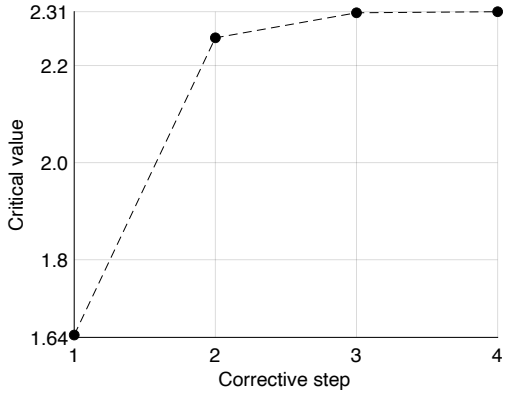
C. A third black-and-white panel



D. A fourth black-and-white panel



E. A fith black-and-white panel



F. A sixth black-and-white panel

FIGURE 2. Graph with six black-and-white panels

Source: The graphs were produced by **?**. Nam libero tempore, cum soluta nobis est eligendi optio, cumque nihil impedit, quo minus id, quod maxime placeat, facere possimus, omnis voluptas assumenda est, omnis dolor repellendus. Aenean fermentum purus id lacus volutpat, a eleifend mi posuere! Mauris nec nunc commodo, vehicula enim nec; vehicula ex. Nullam euismod lorem at eros efficitur: ut ultricies ante fringilla? Nam sagittis sapien id tortor commodo—a pulvinar velit ultricies. Integer ac magna velorci mollis vestibulum. Fusce id ipsum vel magna placerat vehicula. Curabitur ac lobortis justo.

TABLE 1. Basic table with one panel and multicolumns

	Columns 1–2		Columns 3–4	
	Column 1	Column 2	Column 3	Column 4
Line 1:	α	β	γ	δ
Line 2:	ϵ	ϕ	κ	η
Line 3:	κ	ν	π	κ
Line 4:	ψ	μ	ν	ζ

This is a note for the table. Temporibus autem quibusdam et aut officiis debitis aut rerum necessitatibus saepe eveniet, ut et voluptates repudiandae sint et molestiae non recusandae. Pellentesque nec justo aliquet, commodo nulla sed, fringilla odio. Nullam non hendrerit nisi. Curabitur et metus vel velit blandit pharetra. Morbi interdum metus a erat bibendum, nec hendrerit eros ultricies. Vestibulum vel arcu id nulla ultricies commodo. Suspendisse potenti.

aut reiciendis voluptatibus maiores alias consequatur aut perferendis doloribus asperiores repellat.

Suspendisse potenti. Ut venenatis maximus tellus, sit amet mattis lorem finibus nec. Mauris non libero eget ipsum ultricies congue id et eros. Duis nec vehicula nunc. In hac habitasse platea dictumst. Morbi non magna vitae ex fermentum placerat. Quisque eu ultrices velit. Nullam ac odio ac ex tincidunt posuere. Mauris viverra arcu eu metus ultrices, id vestibulum felis posuere.

Fusce eu magna in quam tincidunt placerat. Proin laoreet lacus eget lacinia ullamcorper. Nunc pulvinar, risus quis tempor vestibulum, odio odio fermentum tortor, nec dictum felis libero quis mauris. Vestibulum vel justo a eros efficitur fringilla. Sed at tempus urna. Nulla facilisi. Vivamus sit amet nisl at libero fermentum posuere.

Temporibus autem quibusdam et aut officiis debitis aut rerum necessitatibus saepe eveniet, ut et voluptates repudiandae sint et molestiae non recusandae.

7. A section with cross-references

As usual, it is possible to reference an equation, such as equation (3). It is also possible to reference a section, such as section 5, or a subsection, such as section 4.2. It is also possible to reference an appendix, such as appendix A, or a subsection in an appendix, such as appendix B.2. Of course it is possible to reference figures, such as figure 2, or tables, such as table 1.

8. Conclusion

Summary. At vero eos et accusamus et iusto odio dignissimos ducimus, qui blanditiis praesentium voluptatum deleniti atque corrupti, quos dolores et quas molestias excepturi sint, obcaecati cupiditate non provident, similique sunt in culpa, qui officia deserunt

TABLE 2. Bigger table with several panels

	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
A. A first panel with calligraphic letters							
Line 1:	$\mathcal{A}$	$\mathcal{C}$	$\mathcal{V}$	–	–	$\mathcal{K}$	$\mathcal{A}$
Line 2:	$\mathcal{X}$	$\mathcal{H}$	$\mathcal{O}$	–	–	$\mathcal{K}$	$\mathcal{A}$
B. A second panel with capital letters							
Line 3:	U	B	J	K	A	K	A
Line 4:	N	Y	T	L	T	K	A
Line 5:	G	S	Q	P	Q	K	A
C. A third panel with blackboard-bold letters							
Line 6:	$\mathbb{U}$	$\mathbb{B}$	$\mathbb{J}$	$\mathbb{K}$	$\mathbb{K}$	$\mathbb{K}$	$\mathbb{A}$
Line 7:	$\mathbb{N}$	$\mathbb{Y}$	$\mathbb{T}$	$\mathbb{L}$	$\mathbb{T}$	$\mathbb{U}$	$\mathbb{E}$
Line 8:	$\mathbb{G}$	$\mathbb{S}$	$\mathbb{Q}$	$\mathbb{P}$	$\mathbb{Q}$	$\mathbb{K}$	$\mathbb{P}$
D. A fourth panel with numbers							
Line 9:	1.0%	2.3%	4.5%	9.0%	9.8%	91.2%	0
Line 10:	∞	23	1	90	33	4.0%	0
Line 11:	–	–	1.2	4.4	0	9.0%	0

Note: Temporibus autem quibusdam et aut officiis debitis aut rerum necessitatibus saepe eveniet, ut et voluptates repudiandae sint et molestiae non recusandae. Ut aut reiciendis voluptatibus maiores alias consequatur aut perferendis doloribus asperiores repellat.

mollitia animi, id est laborum et dolorum fuga. At vero eos et accusamus et iusto odio dignissimos ducimus, qui blanditiis praesentium voluptatum deleniti atque corrupti, quos dolores et quas molestias excepturi sint.

Implications. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Nulla facilisi. Curabitur suscipit metus eget quam consequat, eget condimentum justo consectetur. Donec interdum ante nec felis fringilla, a rhoncus magna dapibus. Sed ultricies odio et magna consequat, ut posuere felis vehicula. Vivamus at commodo nisl. Integer sodales eros a metus efficitur, eu tincidunt leo ullamcorper. Sed fermentum tellus nec nisi lobortis, vel pharetra neque mollis. Cras non dolor ut ex semper lobortis. Vivamus sit amet sapien in elit sodales luctus. Donec a tortor ut elit consequat mollis ac id metus. Maecenas vehicula, turpis at lacinia interdum, dolor dolor pretium turpis, non fermentum purus magna at est.

Next steps. Sed in purus nec nulla vulputate scelerisque. Curabitur rutrum aliquet sollicitudin. Suspendisse dapibus metus nunc, id tempus orci accumsan at. Sed rutrum purus velit, vel sollicitudin risus bibendum sed. Sed suscipit arcu ut purus malesuada dictum. Vivamus nec posuere neque. Sed consequat, odio sit amet cursus tincidunt, nulla nunc vulputate elit, ac pharetra eros metus nec ex. Vivamus at ligula id odio auctor blandit a et velit. Suspendisse potenti. Nunc efficitur est id tortor consectetur, sed convallis velit

vulputate. Phasellus lacinia magna nec neque viverra ullamcorper.

References

Bruhin, Adrian, Helga Fehr-Duda, and Thomas Epper. 2010. "Risk and Rationality: Uncovering Heterogeneity in Probability Distortion." *Econometrica* 78 (4): 1375–1412.

Bruhin, Adrian, Ernst Fehr, and Daniel Schunk. 2019. "The Many Faces of Human Sociality: Uncovering the Distribution and Stability of Social Preferences." *Journal of the European Economic Association* 17 (4): 1025–1069.

Fudenberg, Drew, Jon Kleinberg, Annie Liang, and Sendhil Mullainathan. 2022. "Measuring the Completeness of Economic Models." *Journal of Political Economy* 130 (4): 956–990.

Appendix A. Generic appendix

This is a generic appendix. Obcaecati cupiditate non provident, similique sunt in culpa, qui officia deserunt mollitia animi, id est laborum et dolorum fuga. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

A.1. Generic subsection

This is a generic subsection in the appendix. Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat.

In efficitur mi sed eros tincidunt tempus. Cras ut neque vehicula, convallis odio in, lacinia orci. Vivamus et nunc vestibulum, efficitur eros vitae, bibendum justo. Aenean tincidunt ligula ut augue pulvinar, ut placerat risus accumsan. Integer pellentesque odio ac commodo dictum. Ut ut justo a mi consequat vestibulum.

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A.2. Subsection with assumptions and results

This subsection displays an assumption and results in the appendix to illustrate how they are typeset and numbered. First is an assumption:

ASSUMPTION A1. *Similique sunt in culpa, qui officia deserunt mollitia animi, id est laborum et dolorum fuga:*

$$\mathbb{E}(\Omega_{m,n}) = \mathbb{P}(\omega \cdot \mu - \xi) - \sum_{i=0}^{m} \sum_{j=1}^{n} \sigma(i, j) + 123^{56}.$$

Curabitur volutpat ultrices nunc id efficitur. Donec posuere, dui vel gravida elementum, ligula nisi lobortis elit, eu aliquet quam ligula id libero. Sed ac efficitur tur.

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Next is a theorem:

THEOREM A1. *Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum:*

$$X^* = \iint_0^\infty \alpha(i) \cdot \mathcal{A}^2(i) + \mathbb{P}(X \mid Z(i))\, di\, dj, \tag{A1}$$

integer vestibulum sapien nec velit varius, nec scelerisque nunc eleifend. Cras sollicitudin, justo sit amet tempus vehicula, ex ex vulputate nulla, non vestibulum quam tortor nec nisl.

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed aliquam magna vel urna ultrices, sed lacinia nulla mattis. Fusce non nunc nec est mollis malesuada. Here is another theorem based on assumption A1:

THEOREM A2. *Consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua:* $y(\gamma) \geq 3\pi + \cos(\vartheta)$.

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed aliquam magna vel urna ultrices, sed lacinia nulla mattis. Fusce non nunc nec est mollis malesuada. Nullam dignissim nulla sit amet libero facilisis, eget fringilla libero sagittis. Suspendisse potenti. Vivamus fermentum consectetur ante, at rhoncus nisi tristique vel. Vivamus in est quis justo fermentum lacinia ac eu leo. Maecenas nec tempor nisi—as in theorem A2.

A.3. A subsection with math

Here is math and equations in the appendix—see equations (A2) and (A3). Temporibus autem quibusdam ξ et aut officiis debitis aut rerum necessitatibus saepe eveniet ut et voluptates repudiandae sint et molestiae non recusandae $1 - \gamma$. Itaque earum rerum

hic $\mathbb{S}(\zeta^0)$ tenetur a sapiente delectus $\mathcal{B}^\theta$, ut aut reiciendis voluptatibus maiores alias consequatur aut perferendis doloribus asperiores repellat $\mathbb{V}^i$:

$$\mathbb{V}^r = (1-\gamma) \times 0 + \gamma S(z^*)\nu^s + \gamma[1 - S(z^*)]\mathcal{V}^i - c. \tag{A2}$$

Ut enim ad minima veniam, quis nostrum exercitationem ullam corporis suscipit laboriosam, nisi ut aliquid ex ea commodi consequatur? Quis autem vel eum iure reprehenderit qui in ea voluptate velit esse quam nihil molestiae consequatur, vel illum qui dolorem eum fugiat quo voluptas nulla pariatur?

$$\mathbb{E}(N(z)) = \frac{1}{1-\gamma F(z)}. \tag{A3}$$

Appendix B. Another appendix

Here is a second appendix. At vero eos et accusamus et iusto odio dignissimos ducimus, qui blanditiis praesentium voluptatum deleniti atque corrupti.

B.1. Larger figure, without panel, in the appendix

Here is a large, simple figure in the appendix (see figure A1). At vero eos et accusamus et iusto odio dignissimos ducimus, qui blanditiis praesentium voluptatum deleniti atque corrupti, quos dolores et quas molestias excepturi sint, obcaecati cupiditate non provident, similique sunt in culpa, qui officia deserunt mollitia animi, id est laborum et dolorum fuga.

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Nullam fringilla, risus sit amet tincidunt sagittis, ligula nisi suscipit nisi, nec vulputate libero odio sit amet metus. Sed auctor elit nec orci venenatis, in dignissim lacus venenatis. Curabitur auctor odio sit amet leo molestie, vel lacinia sem congue. Integer id interdum metus. Ut ultrices ultricies lorem eget egestas. Integer efficitur libero id sapien posuere, at laoreet mauris consectetur. Nulla facilisi. Sed dapibus lectus at lacus interdum, ac vehicula dui bibendum. In hac habitasse platea dictumst. Sed luctus metus quis libero ultrices, vitae fringilla purus varius. Sed efficitur suscipit felis vel dapibus. Nunc condimentum laoreet ipsum, ut faucibus risus sodales sed. Sed dignissim, magna vel suscipit fermentum, lectus lorem suscipit tortor, eu suscipit elit tortor non dolor.

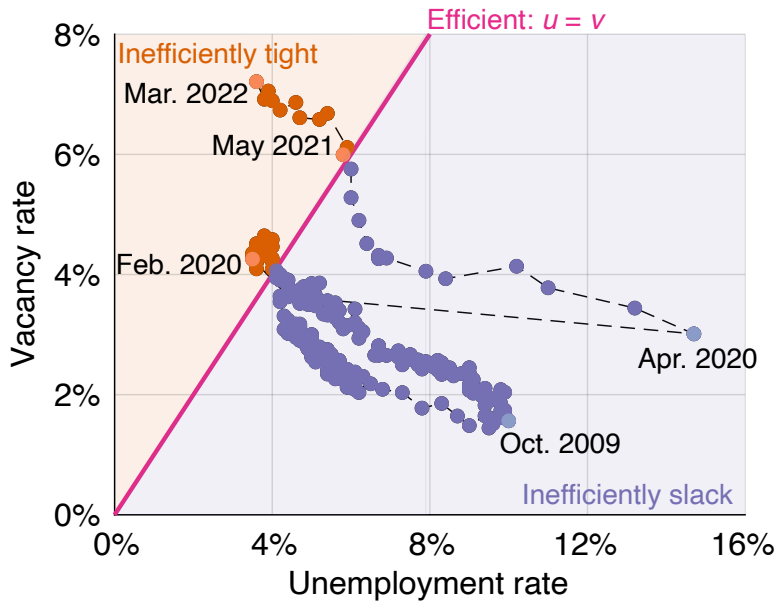

FIGURE A1. A larger graph in the appendix

This is the note for the larger graph. Nam libero tempore, cum soluta nobis est eligendi optio, cumque nihil impedit, quo minus id, quod maxime placeat, facere possimus.

B.2. Subsection with references

Here is a sentence with some references in text: **??** found something but that is an uncommon result. The references can also go in parentheses at the end of the sentence (**??**). The references go to the reference list at the end of the main text—so appendix and main text share a common reference list.

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

B.3. Subsection with a foonote

Here is a sentence with a footnote.[6] The numbering of the footnotes, just like the numbering of the pages, continues from the main text to the appendix.

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[6] Nemo enim ipsam voluptatem quia voluptas sit aspernatur aut odit aut fugit, sed quia consequuntur magni dolores eos qui ratione voluptatem sequi nesciunt.

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Appendix C. Last appendix with text

This is a last appendix with a bit of text.

C.1. A first subsection

Sed vestibulum ex a tristique lacinia. Integer interdum magna vel magna rutrum fermentum. Maecenas sed mi in nunc convallis rutrum. Vivamus dapibus bibendum est, ac tincidunt ipsum fermentum id. Nunc id est turpis. Suspendisse potenti. Sed ac laoreet nulla, eu sollicitudin libero. Suspendisse tempus orci nec mauris volutpat eleifend. Integer nec tristique libero. Sed vehicula ipsum sit amet magna accumsan, nec pulvinar nisl consequat. In ac hendrerit turpis. Sed aliquet luctus mauris, vitae congue turpis. Nullam blandit lacus vel interdum eleifend.

C.2. A second subsection

Nam pretium mauris eros, nec sollicitudin risus tincidunt a. Vivamus in augue vitae ligula scelerisque dapibus. Integer eget metus aliquet, efficitur nibh eget, pharetra eros. Suspendisse luctus interdum ex id suscipit. Donec quis augue mauris. Nulla ut erat eget nisl hendrerit malesuada. Vivamus eu tortor sit amet sem fringilla eleifend. In hac habitasse platea dictumst. Suspendisse potenti. Ut eget libero sed orci tempor ullamcorper:

$$S^*(z) = \frac{\alpha}{1-\gamma(1-\alpha)} > \alpha. \tag{A4}$$

C.3. A third subsection

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed aliquam magna vel urna ultrices, sed lacinia nulla mattis. Fusce non nunc nec est mollis malesuada. Nullam dignissim nulla sit amet libero facilisis, eget fringilla libero sagittis. Suspendisse potenti. Vivamus fermentum consectetur ante, at rhoncus nisi tristique vel. Vivamus in est quis justo fermentum lacinia ac eu leo. Maecenas nec tempor nisi. Sed interdum, nunc ac dapibus lacinia, nunc neque rutrum urna, vel dignissim lectus turpis eu lorem. Donec commodo justo a eros malesuada, eget vulputate tortor accumsan. Sed ac pulvinar nulla. Etiam quis felis dapibus, vulputate metus eu, finibus nunc. Sed vel sodales dui. Nam

venenatis dolor non orci tempus fermentum. Vivamus sodales justo a ligula cursus aliquet. Sed fringilla nunc vitae justo finibus, id placerat lectus sodales.