My Dissertation

by

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Dissertation presented for the degree of Doctor of Philosophy in Economics in the Faculty of Economic and Management Sciences at Stellenbosch University

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Declaration

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Abstract

My Dissertation

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Dissertation: PhD (Economics)
April 2025

In this dissertation...

Our results show...

Uittreksel

My Proefskrif
(“My Dissertation”)

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Proefskrif: PhD (Ekonomie)
April 2025

In hierdie proefskrif...

Ons resultate dui aan...

Acknowledgements

I would like to express my sincere gratitude to the following people:

- My supervisor...
- My family...

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Nomenclature

Variables

θ	elasticity of demand	
$distance$	population-weighted distance	[km]

Vectors

$\boldsymbol{\beta' w}_{idt}$	set of gravity covariates

Subscripts

i	importer
j	exporter
t	period

Acronyms

MNO	mobile network operator
OLS	ordinary least squares
PPML	Poisson Pseudo-Maximum Likelihood

Chapter 1

Chapter Heading

This is an R Markdown (`.Rmd`) document. Markdown is a simple formatting syntax for authoring HTML, PDF, and MS Word documents. For more details on using R Markdown see this link. When you click the **Knit** button (or `Ctrl + Shift + K`) a document will be generated based on the content of this document, as well as the underlying LaTeX template at `styles/template.tex`.

1.1 Section heading

Adipiscing magna bibendum taciti sed nascetur consequat: pretium vivamus facilisi. Natoque libero at, habitasse risus, lacus duis primis sollicitudin potenti pulvinar. At eu tellus pellentesque dignissim inceptos pulvinar dictumst. Netus vulputate phasellus, cursus rhoncus taciti, ad maecenas, turpis nisi dignissim – magnis phasellus augue phasellus phasellus fusce lacinia?

1.1.1 Subsection heading

Dolor mus proin ridiculus nisl fusce quis nulla natoque condimentum tellus. Condimentum vitae congue fusce, primis metus congue. Mus eleifend sociosqu; cum viverra dis porta fusce vestibulum. Rutrum class nec – taciti congue rhoncus, vel vivamus id nisl porttitor himenaeos enim vitae velit vel

1.1.1.1 Subsubsection heading

Lorem bibendum leo augue lobortis duis, sed, nullam eget porta lobortis dictumst est vulputate. Facilisi taciti metus torquent suspendisse, malesuada viverra commodo tincidunt vestibulum integer. Tempor eu rhoncus placerat mattis ornare diam etiam. Ridiculus mi, egestas cum aenean, mattis pellentesque velit in imperdiet vivamus

Paragraph heading Amet leo taciti hac, facilisis ad quisque torquent suscipit risus, felis velit. Porttitor aliquet eros cubilia nibh risus torquent integer quis. Mus cras ultrices accumsan id, ridiculus pharetra. Praesent imperdiet mauris ligula semper urna lobortis venenatis pharetra ridiculus justo dignissim?

Chapter 2

Code Chunks

When you knit this file a document will be generated based on its contents as well as the output of any code chunks embedded within the file. You can embed an R code chunk, like the one `cars` below, with `Ctrl + Alt + I`. The chunk label for each chunk, e.g., `cars`, is assumed to be unique within the document.

```
summary(cars)
```

```
##      speed           dist
##  Min.   : 4.0   Min.   :  2.00
##  1st Qu.:12.0   1st Qu.: 26.00
##  Median :15.0   Median : 36.00
##  Mean   :15.4   Mean   : 42.98
##  3rd Qu.:19.0   3rd Qu.: 56.00
##  Max.   :25.0   Max.   :120.00
```

One of the most crucial code chunks in an R Markdown document is the `setup` code chunk placed at the beginning of the document (after the YAML header). It can be used to load packages and data, and configure the default behaviour of code chunks, used throughout the remainder of the document. Default chunk options are set globally using `knitr::opts_chunk$set` with arguments such as `echo`, `warning`, and `message`.[1] Learn more about code chunk options at this link.

With `source`, you can load scripts of code stored elsewhere in your directory. In the example below, all custom functions stored in `code/functions.R` are loaded, e.g., the `hello_function` which prints the name stored in the YAML metadata. It may be worthwhile to run `source("code/functions.R", local = knitr::knit_global())` in your setup chunk, making your own functions accessible throughout your `.Rmd` document.

```
source("code/functions.R", local = knitr::knit_global())
hello_function()
```

```
## Hallo Johnny Elvis Bravo! This a sourced function.
```

[1] For example, the code chunk option `echo` controls whether the code in an code chunk is printed in the final document. This is set globally to `echo = F` in the `setup` chunk.However, in an individual code chunk, like `cars`, you can specify `echo = T` if you want its code printed.

Chapter 3

Basics

3.1 Lists

Itemized lists can be created using Markdown syntax like this:

- Item 1
- Item 2
- Item 3

Numbered lists can be created using Markdown syntax like this:

1. Item 1
2. Item 2
3. Item 3

These are equivalent to using the LaTeX environments `itemize` and `enumerate`.

3.2 Equations and symbols

Equations are created with the help of the LaTeX package `amsmath`. An equation must read like part of the text, using a full stop to indicate the end of the sentence:

$$e^{i\theta} = \cos\theta + i\sin\theta. \tag{3.1}$$

End an equation with a comma if used in the middle of a sentence and start the subsequent text in lower case. For example, Euler's identity is

$$e^{i\pi} + 1 = 0, \tag{3.2}$$

where e is Euler's number, the base of natural logarithms. Here is another pair of equations, this time using & to horizontally align multiple lines on their equals signs:

$$a^2 + b^2 = c^2 \tag{3.3}$$
$$e^{i\pi} + 1 = 0. \tag{3.4}$$

A series of equations within the `subequations` LaTeX environment share a common label. In the `gather` LaTeX environment, equations are typeset sequentially. Using these

environments together produces, for example:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j}\left[\rho u_j\right] = 0 \tag{3.5a}$$

$$\frac{\partial}{\partial t}\left(\rho u_i\right) + \frac{\partial}{\partial x_j}\left[\rho u_i u_j + p\delta_{ij} - \tau_{ji}\right] = 0, \quad i = 1, 2, 3 \tag{3.5b}$$

$$\frac{\partial}{\partial t}\left(\rho e_0\right) + \frac{\partial}{\partial x_j}\left[\rho u_j e_0 + u_j p + q_j - u_i \tau_{ij}\right] = 0 \tag{3.5c}$$

Markdown syntax can also be used. An equation is created below with a pair of `$$` (double `$`). This is particularly useful to observe a visual preview of the equation in your `.Rmd` document.

$$f_X(x) = \left(\frac{\alpha}{\beta}\right)\left(\frac{x}{\beta}\right)^{\alpha-1} e^{-\left(\frac{x}{\beta}\right)^{\alpha}}; \alpha, \beta, x > 0.$$

A mathematical expression within a line of text can be created with the use of a pair of `$` (single `$`), like this $\sum_{i=2}^{\infty}\{\alpha_i^{\beta}\}$, also providing a visual preview of the expression.

Symbols representing values of properties should be printed in italics, but SI units and names of functions (e.g. sin, cos and tan) should not be printed in italics. There should be a small hard space between a number and its unit. This can be achieved with, e.g., `\qty{120}{km}` which produces 120 km. Use the `siunitx` package to typeset numbers, angles and quantities with units:

`\num{1.23e3}`	→	1.23×10^3
`\ang{30}`	→	30°
`\qty{20}{N.m}`	→	20 N·m

3.3 FLOATS

Floating environments in LaTeX prevent figures and tables from being split across pages. Their placement can be controlled by the following placement specifiers:

- `h`: Here at approximately the same point in the source text.
- `t`: Top of the page.
- `b`: Bottom of the page.
- `p`: A special page for floats only.
- `!`: Override LaTeX's internal parameters.
- `H`: Precisely at this location in the source (with the `float` LaTeX package).

Specifiers can also be combined, e.g., `!b` forces placement at the bottom of a page. You may also considering making use of the LaTeX package `placeins` by specifying the `\FloatBarrier` command twice to create barriers that figures cannot escape.

3.4 FIGURES

A figure's placement can be set in its particular code chunk's options, as in the `waterplants` chunk with `fig.pos = "h"`. Other chunk options for figures include, among others, `fig.cap`, `fig.height`, `fig.width` and `out.width`. The default behavior for figures arising from all code chunks is set in the `setup` chunk with `knitr::opts_chunk$set`. Existing figures or images can be included with `knitr::include_graphics`, which can import `PDF`, `PNG`, or `JPG` files like Figure 3.1.

Figure 3.1 Water plants

Plots can also be created using, e.g., `ggplot` from the `tidyverse`, as shown below. The resulting plot, Figure 3.2, is embedded in the document.

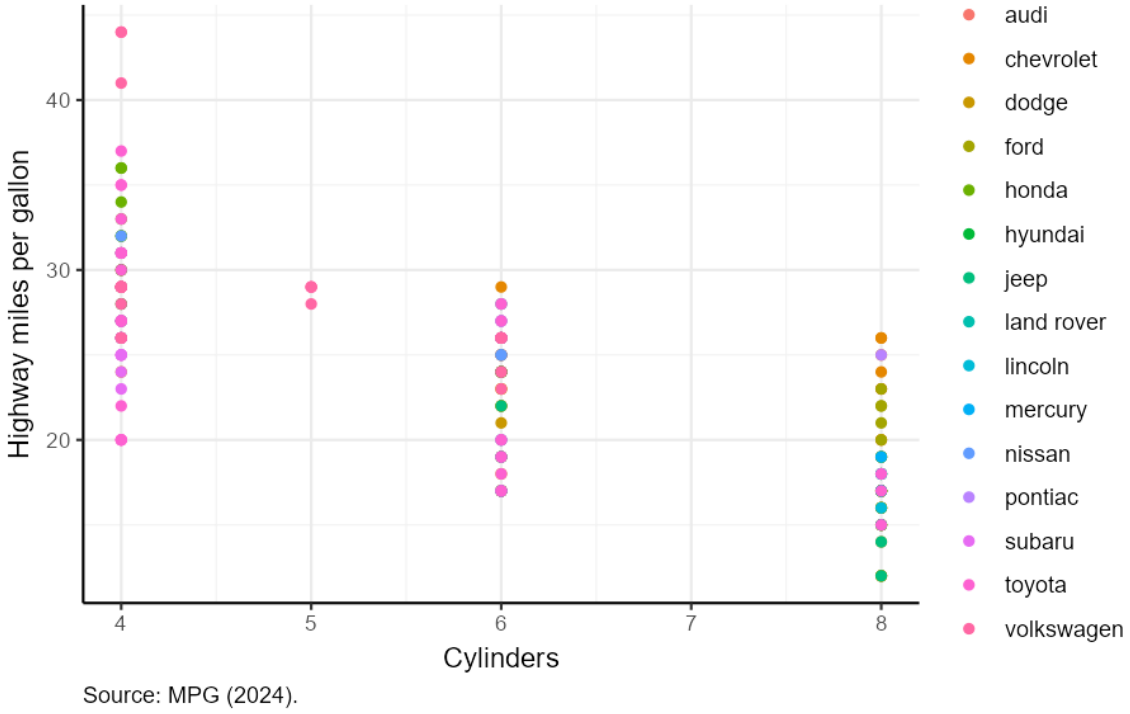

Figure 3.2 Manufacturer fuel efficiency

3.5 TABLES

To create tables, I recommend using the `kbl` and `kable_styling` functions from the `kableExtra` R package. Table 3.1 is created with the code chunk below.

Table 3.1 Caption centered above table

	mpg	cyl	disp	hp
Mazda RX4	21.0	6	160	110
Mazda RX4 Wag	21.0	6	160	110
Datsun 710	22.8	4	108	93
Hornet 4 Drive	21.4	6	258	110
Hornet Sportabout	18.7	8	360	175
Valiant	18.1	6	225	105

My footnote: This is my table footnote.

The first four columns of the `mtcars` data frame are used as input for `kbl`, which generates a basic table. The function includes several useful arguments:

- `digits = 2`: Sets the number of decimal places.
- `booktabs = TRUE`: Uses `booktabs` for a more appealing formatting.
- `linesep = ""`: Removes default line separators.
- `centering = TRUE`: Centres the table.
- `position = "H"`: Positions the table precisely with the float specifier.
- `escape = TRUE`: `FALSE` allows the use of special LaTeX characters.
- `table.envir = "table"`: Sets the LaTeX environment.
- `caption = "Caption centered above table"`: Adds a caption above the table.

In turn, `kable_styling` enhances the appearance of the table by setting, e.g., the table's font size. Additionally, a footnote is added using `footnote`, with arguments that set the title, content and layout of the footnote.

3.6 FOOTNOTES

Footnotes provide additional information without cluttering the main text and are inserted using `\footnote{}` in LaTeX or `^[]` in Markdown. See this example.[1] Footnotes can also be managed with `\footnotemark` and `\footnotetext` for more control over their placement and numbering.

- `\footnotemark` adds a superscript number at the text location, and can be used in LaTeX when you need to refer to the same footnote multiple times or to place

[1] This is an example of a footnote.

the marker manually. In Markdown, the equivalent is using `[^1]` to reference a footnote.
- `\footnotetext` is used to input the footnote's text and can be placed anywhere in the text to match the corresponding `\footnotemark`. In Markdown, define the footnote content at the document's end with `[^1]: Text of the footnote`.

3.7 Acronyms

Using the `acronym` LaTeX package, acronyms are defined in the `acronym` environment of the `matter/nomenclature.Rmd` file, making them available throughout your document. Acronyms are defined with `\acro{key}[short]{long}` where `short` the abbreviated form, and `long` the full form, e.g., `\acro{arpu}{ARPU}{average revenue per unit}`. In most cases, use `\ac{key}` to insert an acronym. It will automatically expand to its full form the first time and to its short form on subsequent references. Here are some variations on the use of `\ac{key}`.

- `\ac{ppml}` produces Poisson Pseudo-Maximum Likelihood (PPML) the first time, and PPML the second time.
- `\acf{ols}` uses the long form ordinary least squares (OLS) every time.
- `\acs{ols}` uses the short form OLS every time.
- Plural forms can also be automatically managed by adding an `p` to the command, e.g., `\acp{mno}` for mobile network operators (MNOs).

Notably, the `acronym` package is set up with the `printonlyused` option, implying that the list of acronyms in your final document (printed in the "Nomenclature" chapter) will only include those used at least once in the document.

3.8 Referencing, Citations, and Cross-Referencing

The bibliography file is stored at `matter/mybib.bib`, formatted in `bibtex` with unique keys for each entry. The `natbib` package manages citations effectively, supporting a range of styles:

- `\citet{key}` for textual citations (e.g., Anderson et al. (2016)). `\citet*{key}` expands to list all authors.
- `\citep{key}` for parenthetical citations (e.g., (Anderson et al., 2016)), with `\citep*{key}` for a full author list.
- `\citeauthor{key}` and `\citeyear{key}` (`\citeyearpar{key}`) cite the author(s) or year (in parentheses), respectively., e.g., Anderson and Van Wincoop, 2003, and (2003).

Markdown offers similar functionality using `@key` for textual citations and `[@key]` for parenthetical citations. The `-@key` form cites just the year.

For bibliography management, I recommend using Zotero to automatically export collections of bibliography entries to `matter/mybib.bib`. See **Better BibTeX**, **Citations in R**

Markdown's Visual Mode, and **ZotFile** for additional tools making citation and reference management easier.

Cross-referencing is made possible with LaTeX package `hyperref`, and streamlined with the `cleveref` package, configured with `\usepackage[capitalize,noabbrev]{cleveref}` to capitalize and use full names (e.g., Figure, Equation) in references:

- `\label{key}` marks a target location.
  - Tables and figures are automatically labelled in R Markdown, using code chunk names with an appropriate prefix as keys, e.g., `fig:fancyplot` and `tab:tab1`.
  - Headings are also automatically labelled, taking their text (in lower-case, spaces swapped with hyphens) as keys, e.g. the "Equations and symbols" section is labelled as `equations-and-symbols`.
- `\ref{key}` retrieves a basic reference.
  - `\ref{fig:fancyplot}` produces 3.2
  - `\ref{tab:tab1}` produces 3.1
  - `\ref{eq:Euler1}` produces 3.1
  - `\ref{equations-and-symbols}` produces 3.2.
- `\eqref{key}` provides a parenthesized number for equations
  - `\eqref{eq:Euler1}` produces (3.1).
- `\cref{key}` offers context-dependent referencing, adapting to the type of the referenced object.
  - `\cref{fig:fancyplot}` produces Figure 3.2
  - `\cref{tab:tab1}` produces Table 3.1
  - `\cref{eq:Euler1}` produces Equation (3.1)
  - `\cref{equations-and-symbols}` produces Section 3.2.
- `\notag` is used to suppress the numbering of an equation when it is unnecessary, ensuring that un-referenced equations remain unnumbered.

With both citations and cross-references, dynamic links are created, aiding document navigation.

Chapter 4

Conclusion

Ipsum mattis rhoncus ante commodo pulvinar phasellus! Pretium dapibus, suspendisse, maecenas, sem neque mi ultricies? A in fringilla, felis diam suscipit pellentesque aliquam magnis? Imperdiet luctus; torquent taciti id, ultrices cursus egestas vel, eu taciti congue nibh fringilla ullamcorper habitant natoque cum.

Sit himenaeos convallis ac molestie felis mattis vulputate ante leo luctus primis id. Habitasse hac senectus luctus lectus tincidunt rhoncus quam interdum lacinia congue. Suspendisse sagittis lobortis non aliquam taciti nunc. Placerat felis ut ornare, neque: massa cubilia – ultricies inceptos leo integer?

Sit arcu lobortis parturient cras, tristique convallis tempus parturient placerat purus. Congue sociis posuere in, tortor leo ultricies torquent ullamcorper. Vitae gravida faucibus, viverra, himenaeos etiam hendrerit? Aliquet velit natoque mollis conubia fringilla molestie tincidunt, lacus malesuada nascetur metus, eros dictum porta, tincidunt; auctor duis facilisis aliquam aenean semper eleifend molestie libero?

Ipsum augue ac sem: at phasellus volutpat velit placerat facilisis. Porta sociis at tempor: senectus quam neque venenatis. Rhoncus metus, tristique, donec dictumst posuere: gravida erat montes ultricies. Tempus quam potenti per sociis aliquet platea pulvinar nascetur sem posuere mauris nam ad lacus interdum rutrum?

Sit malesuada nisl cum turpis porta elementum fringilla!

Consectetur pellentesque cum consequat maecenas himenaeos sollicitudin mi. Taciti mus vestibulum vitae placerat: facilisi facilisi dignissim litora? Dui pulvinar tellus gravida justo odio ultrices facilisis libero class. Hendrerit risus purus id tortor magna gravida libero, scelerisque, luctus tellus lacinia interdum purus

Appendix A

Mathematics

An inversion formula: Let $g : \mathbb{R}^+ \to \mathbb{R}$ be bounded and right continuous, and let $\varphi(\alpha) := \int_0^\infty e^{-\alpha t} g(t)\, dt$ denote its Laplace transform. Then, for every $t > 0$,

$$g(t) = \lim_{\varepsilon \to 0} \lim_{\lambda \to \infty} \varepsilon^{-1} \sum_{\lambda t < k \le (\lambda+\varepsilon)t} \frac{(-1)^k}{k!} \lambda^k \varphi^{(k)}(\lambda). \tag{A.1}$$

Solutions of systems of ODEs: Let $\mathbf{v}(\mathbf{x}, \boldsymbol{\alpha})$ denote a parametrized vector field ($\mathbf{x} \in U$, $\boldsymbol{\alpha} \in A$) where U is a domain in $\mathbb{R}^n$ and the parameter space A is a domain in $\mathbb{R}^m$. We assume that $\mathbf{v}$ is C^k-differentiable as a function of~$(\mathbf{x}, \boldsymbol{\alpha})$, where~$k \ge 2$. Consider a system of differential equations in~U:

$$\mathbf{x} = \mathbf{v}(\mathbf{x}, \boldsymbol{\alpha}), \qquad \mathbf{x} \in U \tag{A.2}$$

Fix an initial point $\mathbf{p}_0$ in the interior of U, and assume $\mathbf{v}(\mathbf{p}_0, \boldsymbol{\alpha}_0) \neq \mathbf{0}$. Then, for sufficiently small t, $|\mathbf{p} - \mathbf{p}_0|$ and $|\boldsymbol{\alpha} - \boldsymbol{\alpha}_0|$, the system~(A.2) has a unique solution $\mathbf{x}_{\boldsymbol{\alpha}}(t)$ satisfying the initial condition $\mathbf{x}_{\boldsymbol{\alpha}}(0) = \mathbf{p}$, and that solution depends differentiably (of class~C^k) on t, $\mathbf{p}$ and $\boldsymbol{\alpha}$.

Stirling's formula:

$$\Gamma(z) \sim e^{-z} z^{z-1/2} \sqrt{2\pi} \left[1 + \frac{1}{12z} + \frac{1}{288z^2} - \frac{139}{51840z^3} + \dots \right], \quad z \to \infty \text{ in } |\arg z| < \pi. \tag{A.3}$$

Bézier curves: Given z_1, z_2, z_3, z_4 in $\mathbb{C}$, define the B'ezier curve with control points z_1, z_2, z_3, z_4 by

$$z(t) := (1-t)^3 z_1 + 3(1-t)^2 t z_2 + 3(1-t) t^2 z_3 + t^3 z_4, \qquad 0 \le t \le 1.$$

Because $(1-t)^3 + 3(1-t)^2 t + 3(1-t)t^2 + t^3 = (1-t+t)^3 = 1$ and all summands are positive for $0 \le t \le 1$, $z(t)$ is a convex combination of the four points~z_k, hence the curve defined by $z(t)$ lies in their convex hull. As t varies from~0 to~1, the curve moves from z_1 to~z_4 with initial direction $z_2 - z_1$ and final direction $z_4 - z_3$.

Maxwell's equations:

$$\mathbf{B}' = -c\nabla \times \mathbf{E}$$
$$\mathbf{E}' = c\nabla \times \mathbf{B} - 4\pi \mathbf{J}.$$

Residue theorem: Let f be analytic in the region G except for the isolated singularities a_1, $a_2, \ldots, a_m$. If γ is a closed rectifiable curve in G which does not pass through any of the points a_k and if $\gamma \approx 0$ in G, then

$$\frac{1}{2\pi i}\int_\gamma f = \sum_{k=1}^{m} n(\gamma; a_k)\,\mathrm{Res}(f; a_k).$$

Maximum modulus principle: Let G be a bounded open set in $\mathbb{C}$ and suppose that f is a continuous function on $\bar{G}$ which is analytic in G. Then

$$\max\{|f(z)| : z \in \bar{G}\} = \max\{|f(z)| : z \in \partial G\}.$$

Jacobi's identity: Define the *theta function* ϑ by

$$\vartheta(t) = \sum_{n=-\infty}^{\infty} \exp(-\pi n^2 t), \qquad t > 0.$$

Then

$$\vartheta(t) = t^{-1/2}\vartheta(1/t).$$

Appendix B

Experiments

Adipiscing penatibus sapien suspendisse cras suscipit cum at. Phasellus nulla aenean arcu leo nibh, habitant leo – vehicula curae nunc odio, facilisi tristique magnis nibh tellus!

Adipiscing senectus justo, fermentum ridiculus fringilla porta pretium dapibus vulputate diam nascetur. Tristique senectus vitae morbi neque per maecenas massa ornare metus.

Consectetur bibendum odio sollicitudin molestie inceptos hac tortor. Taciti pulvinar nisi ultrices etiam platea felis augue egestas ultrices. Tristique sed lectus litora himenaeos curae? Ultrices leo purus, augue porttitor primis posuere erat tincidunt facilisis blandit vehicula. Magnis mattis enim ultrices pharetra!

Amet proin litora aliquam ultrices cubilia eleifend pulvinar. Accumsan erat nam commodo neque, vivamus: libero, massa aptent curae consequat. Sem hendrerit conubia bibendum phasellus; mi; cursus diam iaculis, aenean turpis risus, hendrerit libero fusce! Hac cursus quis class nascetur ornare, nam proin dictumst. Massa dapibus lectus ad tortor vivamus facilisi tellus tortor molestie inceptos. Nam ligula magna!

Ipsum facilisis pellentesque commodo eleifend eros eros sollicitudin – non cum primis aliquet? Neque torquent dui porta facilisis dignissim nec nibh, tellus vestibulum suspendisse. Magna duis at tincidunt fringilla!

Amet auctor maecenas ad vitae sed posuere sodales dui tristique turpis netus. Nam ut nulla litora eleifend porttitor auctor proin suscipit vitae metus. Sociis enim inceptos taciti hendrerit penatibus ante proin proin hendrerit!

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