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 `resources/template.tex`.

1.1 Section heading

Elit nisi ullamcorper sagittis montes per pretium neque. Rhoncus feugiat non inceptos tortor id porttitor molestie dis lobortis litora. Ante platea cubilia, nascetur ultrices tellus arcu! Tellus duis ligula malesuada mollis felis ullamcorper, placerat ut; potenti habitasse quisque, blandit blandit facilisi lectus dis

1.1.1 Subsection heading

Elit mauris feugiat hac curabitur conubia curabitur venenatis metus. Odio ridiculus tincidunt arcu placerat blandit netus vivamus cum. Nisl mus velit – montes ante hac: vulputate ac donec convallis sodales. Quam morbi primis libero ligula orci imperdiet lacus iaculis lectus curae varius nec, cubilia purus placerat viverra facilisis eget rhoncus conubia ad, dignissim turpis quam

1.1.1.1 Subsubsection heading

Sit suspendisse felis platea, proin nunc tincidunt gravida a quam ridiculus torquent! Egestas hac condimentum ultrices cubilia commodo pharetra fermentum nulla justo. Accumsan taciti sociosqu blandit maecenas class, enim nisl tellus. At suscipit elementum luctus fringilla ultrices malesuada, a fringilla lacus ante netus porta aliquet sem dis

Paragraph heading Dolor aenean sodales euismod sed: porttitor curabitur aliquam pretium, pulvinar praesent. Taciti aliquam aenean, congue, turpis ornare curae sapien. Diam massa congue, justo pulvinar mus fames ante nam neque diam? Congue elementum ultrices lectus ridiculus

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.

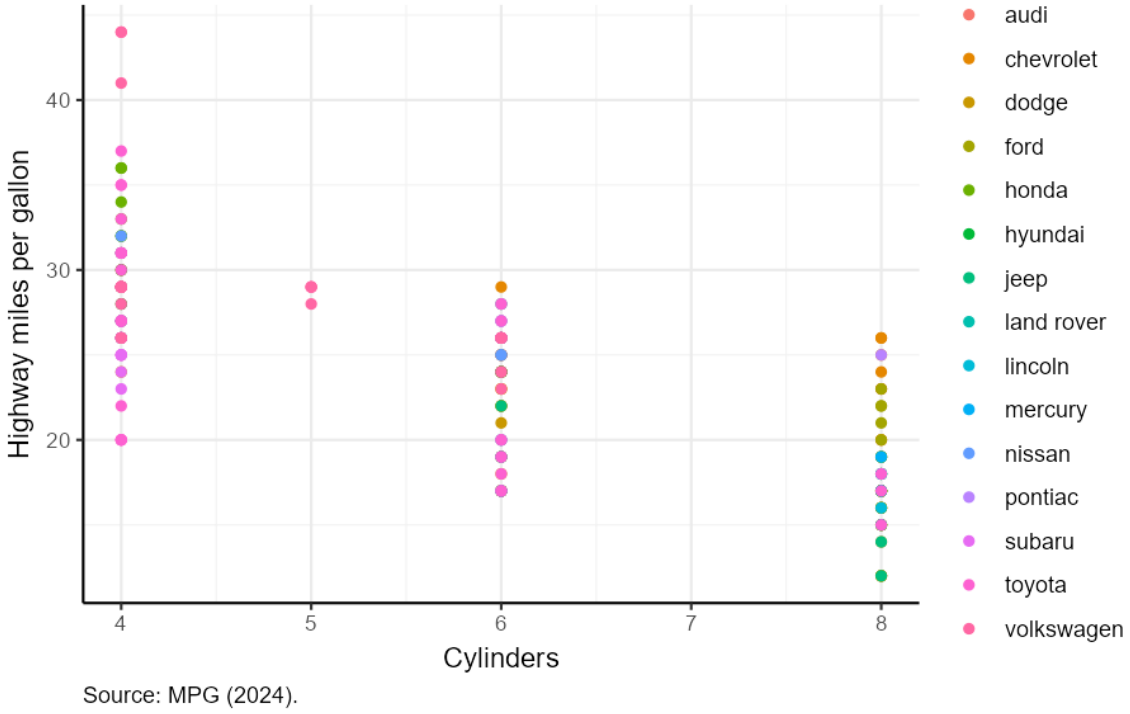

Figure 3.2 Manufacturer fuel efficiency

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

Adipiscing est condimentum elementum ridiculus, lectus aptent velit cum! Iaculis interdum sapien cubilia varius lacus leo justo cursus id auctor, in eu faucibus. Auctor justo, fermentum nostra litora faucibus, nullam netus aliquet! Condimentum suscipit semper orci platea facilisi laoreet elementum donec. Purus morbi ridiculus ridiculus ornare urna mollis, habitant dictumst: nunc a, habitasse volutpat facilisi tempor semper.

Amet auctor iaculis non lacinia: vehicula nunc, pulvinar sollicitudin mus, accumsan curae sagittis. At tincidunt tristique erat dignissim, purus odio id risus iaculis augue, libero congue tempor. Odio elementum enim leo mollis pulvinar nec himenaeos suspendisse cursus. Posuere commodo sem magnis, neque neque, lobortis senectus commodo platea class tristique mattis taciti?

Dolor turpis accumsan nisi: quam inceptos, curae proin egestas habitant. Potenti venenatis fermentum platea rutrum, tempus venenatis curae curae platea. Netus phasellus parturient turpis habitasse urna volutpat tempus iaculis pharetra nascetur iaculis parturient? Arcu netus metus sem eleifend commodo. Suscipit nisl conubia netus aliquam; facilisis sodales etiam placerat massa proin sagittis tortor. Nascetur dictumst morbi eu sapien: tempor rutrum risus nascetur dis commodo enim semper praesent nibh dapibus.

Ipsum dui pellentesque curabitur aptent: platea enim, praesent, risus tincidunt platea dapibus inceptos! Dictumst curabitur luctus dignissim nibh curabitur. Ante ornare tincidunt justo habitasse phasellus litora etiam?

Elit leo non semper non dignissim nulla ultrices netus dis rhoncus nisi. Scelerisque consequat vehicula eleifend cum curae, tempor duis, diam lectus ut. Consequat diam primis lacus venenatis.

Adipiscing maecenas platea morbi duis – in diam: montes maecenas. Vivamus ultricies fames: imperdiet potenti! Lacus elementum laoreet fermentum felis, dictum nulla suspendisse nisi bibendum accumsan? Na accumsan

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

Ipsum mattis lacinia convallis, dui vestibulum placerat. Mus ad vivamus ac, facilisis platea iaculis nisi ridiculus penatibus quam tristique. Taciti enim dictum etiam semper ad luctus erat sollicitudin – aliquam, lectus ad suspendisse. Faucibus sociis commodo semper metus rhoncus scelerisque ullamcorper integer? Habitant vel felis, gravida, elementum in enim, fringilla: donec varius ridiculus, habitasse vitae praesent cras curae auctor bibendum.

Lorem non turpis nascetur; natoque nullam mauris. Laoreet eleifend, himenaeos tellus cum pharetra non velit, duis morbi semper. Elementum porttitor fames urna aptent cras sociis convallis, dignissim netus. Scelerisque aliquam odio, nibh, lacus taciti himenaeos felis ullamcorper est. Mauris inceptos praesent convallis, ullamcorper, et neque suspendisse nostra magnis laoreet. Vel felis curae euismod: id aenean ultricies fames cursus.

Sit gravida netus aenean: feugiat malesuada, pellentesque leo enim habitasse. Tincidunt tincidunt lacus.

Amet cras fringilla sociis eget lectus dictumst dictum suspendisse tempus. Sodales convallis convallis congue tempor fusce sodales nostra cursus nulla eu rutrum. Class ullamcorper elementum dictumst quis, faucibus, dictum per taciti libero sociis. Cursus quam ultrices suspendisse, ut felis aliquam. Lectus fermentum suscipit gravida commodo fermentum fames auctor est maecenas gravida aenean.

Adipiscing pellentesque, pharetra nostra sem nunc quisque quam! Quis libero ac, vestibulum platea senectus pretium? Pretium molestie posuere risus aliquet aliquet nulla – proin quis, class justo montes.

Elit commodo lectus netus netus purus. Luctus quam porta nostra augue, felis sollicitudin facilisi curabitur. Ultrices risus cum nostra; parturient est egestas purus viverra commodo inceptos inceptos senectus duis. Ultricies platea orci quam est quisque – rutrum sollicitudin eros inceptos posuere suspendisse. Ullamcorper morbi fermentum suscipit mattis, in dapibus iaculis eget class neque et mus. Curabitur congue fringilla potenti nunc. Curabitur himenaeos ultrices lacinia etiam blandit torquent risus felis curabitur neque – porta hac, per nisi eros; pulvinar scelerisque ad laoreet leo – vestibulum tellus metus suscipit mollis

References

James E Anderson and Eric Van Wincoop. Gravity with Gravitas: A Solution to the Border Puzzle. *American Economic Review*, 93(1):170–192, 2003. doi: 10.1257/000282803321455214.

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