Learning Ricardian Equivalence*

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Abstract

This paper tests whether subjects learn to comply with the Ricardian Equivalence proposition in a life cycle consumption laboratory experiment. Our results suggest that Ricardian Equivalence does not hold on average: tax changes have a significant and strong impact on consumption choice. Using individual consumption time series, the behaviour of 56% of our subjects can be classified as inconsistent with the Ricardian Equivalence proposition. Classifying subjects according to rules of thumb that best describe their behaviour, we find that subjects switch less to rules that theoretically violate Ricardian Equivalence in later rounds compared to earlier rounds. This implies that some subjects learn to comply with Ricardian Equivalence by changing their consumption strategy. However, the aggregate effect of taxation on consumption persists, even after eight rounds of repetition.

Keywords Ricardian Equivalence · Rule of Thumb Consumers · Learning · Taxation · Life Cycle Laboratory Experiment

JEL Classification D91 · E21 · H24 · C91

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1 Introduction

The question whether people behave in accordance with the Ricardian Equivalence proposition has been subject to debate among economists, ever since it has first been formulated by David Ricardo in 1820. Generally the evidence seems mixed: While the excellent survey by Seater (1993) suggests that the data support Ricardian Equivalence, many studies are less favourable.\(^1\) However, one of the reasons for evidence against Ricardian Equivalence might be the difficulty to control for confounders in survey or register data. For instance the presence of progressive taxation, political uncertainty, liquidity constraints, heterogeneity in preferences and uncertainty, and other confounders lead to a violation of Ricardian Equivalence in theory, and hence it is hard to infer if Ricardian Equivalence would hold, were these confounders not present. Laboratory experiments may help in this case, as they allow to control for these confounders, or to manipulate them in a controlled way.

Previous experimental research has identified under what conditions Ricardian Equivalence can be expected to hold: Cadsby and Frank (1991) were first to experimentally explore Ricardian Equivalence, and find that the results generally confirm Ricardian Equivalence. Slate et al. (1995) reject Ricardian Equivalence in cases where there exists uncertainty about debt repayment. Di Laurea and Ricciuti (2003) also reject Ricardian Equivalence in treatments with income uncertainty. Finally, Adji et al. (2009) find supporting evidence for Ricardian Equivalence under lump sum taxation, but reject Ricardian Equivalence under distortionary taxation.\(^2\)

While all these studies use overlapping generations (OLG) models as a theor-


\(^2\)See Online Appendix B for a table summarising the existing experimental results on Ricardian Equivalence.
ical basis for the experimental design, Luhan et al. (2014) and Geiger et al. (2016) study consumption behaviour in a multi-period life-cycle consumption setup with two main findings that are relevant for our study. First, Luhan et al. (2014) find that anticipated future changes in prices exert substantially smaller effects on current consumption than predicted by a life cycle model. Second, Geiger et al. (2016) focus on the so-called expectations channel and find that fiscal consolidation (e.g. tax increases) have contractionary effects on consumption.

A question that has not yet been answered is whether people can *learn* to behave according to the Ricardian Equivalence proposition. Insights on learning behaviour are crucial to understand decision-making of individuals who are not perfectly rational. If people learn to improve their decision-making, decisions in otherwise equal circumstances will vary depending on how much learning has happened. Moreover, analysing learning behaviour is particularly important for laboratory experiments, where results are typically judged by how robust they are with respect to learning (Hertwig and Ortmann, 2001). This paper attempts to fill this gap, and answer the question whether people can learn to comply with the Ricardian Equivalence proposition.

The importance of learning has been recognised by a theoretical literature that analyses if individual learning allows to find the optimal consumption function in a life cycle setting. The conclusion from the pioneering work in Allen and Carroll (2001) is quite pessimistic. However, Yıldızoğlu et al. (2014) show that assumptions on bounded rationality and on adaptive expectations are perfectly compatible with sound and realistic economic behaviour, which can converge to the optimal solution. Brown et al. (2009) find in a life-cycle consumption experiment that subjects saved

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3 These findings imply that we can reasonably expect (Ricardian) taxation to have an influence on behaviour in a life-cycle consumption experiment. However neither Luhan et al. (2014) nor Geiger et al. (2016) test whether subjects comply with the Ricardian Equivalence proposition.
much too little at first, but learned to save close to optimal amounts after three or four life cycles of learning.\footnote{More broadly, our research is connected to the literature on learning and strategy evolution (e.g. Arifovic, 1994) in macroeconomic models surveyed by Sargent (1993) or Evans and Honkapohja (2001). In particular, we relate to studies with focus on intertemporal choice problems (Lettau, 1997; Lettau and Uhlig, 1999).}

To analyse learning effects we use a setup similar to Brown et al. (2009). The experimental environment is based on a (25 period) life-cycle consumption model, that is favourable for analysing Ricardian Equivalence in the sense that it is challenging enough to find the optimal consumption rule to observe learning behaviour.\footnote{We focus on individual learning rather than social learning, since the latter is difficult to implement in the laboratory (Brown et al., 2009).}

In our experiment, a Ricardian tax scheme is implemented as a tax cut in early periods of the experiment, followed by a tax increase of the same magnitude in later periods. Introducing such a tax scheme may increase the difficulty to smooth consumption for subjects.\footnote{See subsection 2.1 for an example.} We therefore introduce two different taxing schemes, one that increases the difficulty to smooth consumption and one that decreases it relative to a control treatment with constant taxation. In this way we can analyse the effects of difficulty and Ricardian taxation separately. This is a novel approach with regard to existing experimental studies on Ricardian Equivalence.

Our first main finding is that Ricardian taxation \textit{does} influence consumption decisions. A nonparametric analysis shows that deviations from optimal consumption appear to be larger with the tax scheme that increases the difficulty to smooth consumption compared to the one that decreases the difficulty. Overall, deviations from optimal behaviour are lowest in the treatment with constant taxation. This implies that both difficulty and Ricardian taxation affect consumption behaviour.

Using structural panel data methods to estimate consumption functions allows to
quantify the effect that taxation has on consumption: our second main result is that a tax benefit in early periods increases consumption by about 21% of the tax benefit on average, while a tax increase reduces consumption by 25% of the tax increase. These results are robust to variations in the difficulty to smooth consumption.

Using the same structural estimation strategy on the individual level, our third main finding is that about 56% of the subjects in our sample do significantly react to tax cuts or increases, and thus do not behave according to the Ricardian proposition.

To explain these results, we formally analyse learning effects by comparing behaviour across the eight repetitions of the experiment. While subjects in our experiment appear to learn to improve their consumption decisions, our fourth main finding is that subjects do on average not learn to behave according to the Ricardian Equivalence proposition even after repeating the experimental life cycle eight times.

To understand individual behaviour, we then classify subjects’ behaviour according to different rules of thumb that best describe their behaviour. We find that subjects increasingly change their consumption rules to rules that theoretically imply Ricardian Equivalence in later rounds compared to early rounds. This implies that some subjects learn to comply to Ricardian Equivalence by adjusting their consumption rules.

The remainder of this paper is structured as follows. Section 2 describes the experimental design and the underlying theory. Section 3 reports our results. Section 4 concludes.

2 Theory and Experimental Design

The experiment described in the following section is based on an adapted version of the life cycle model of consumption used in Meissner (2016). One experimental life cycle lasts for $T = 25$ periods. In order to assess learning effects, we repeat
the experiment for a total of eight independent life cycles (rounds). In each period \( t = (1, ..., T) \), subjects decide how much to consume \( (c_t) \) and implicitly how much to save or borrow. There is no discounting, and no interest is paid on savings or debt.\(^7\)

Period income \( y_t \) follows an i.i.d. stochastic process and takes the values of 120 or 250 with equal probability in each period. Subjects have to pay a lump sum tax \( \tau_t \) in every period. The government’s budget constraint requires the amount of total taxes to be collected during the experiment to equal \( \vartheta \). The subjects’ intertemporal budget constraint requires period consumption plus period savings \( (a_{t+1}) \) plus period taxes to equal period wealth, which is defined as \( w_t = y_t + a_t \). Period savings are allowed to be both positive and negative. Savings in the last period \( (a_{T+1}) \) must equal zero, which implies that remaining wealth must be consumed in that period. Subjects start with initial savings, \( a_1 = 1000 \).\(^8\) These two conditions ensure that the intertemporal budget constraint is binding, i.e. \( \sum_{t=1}^{T} y_t + a_1 = \sum_{t=1}^{T} c_t + \vartheta \).

Induced preferences are given by a time-separable CARA utility function: \( u(c_t) = 338[1 - e^{(-\theta c_t)}] \), where the coefficient of absolute risk aversion, \( \theta \), is set to 0.0125.\(^9\) We chose the parameters of our model in order to make the incentives for subjects to behave optimally as salient as possible. This requires sufficient curvature of the utility function around optimal consumption. Moreover, our parametrisation ensures that the payoff function is easy to understand and guarantees an average hourly wage

\(^7\)We explicitly abstract from interest, in order to not further complicate the experiment, and to control for exponential growth bias (Levy and Tasoff, 2015).

\(^8\)One often-stated reason for the violation of Ricardian Equivalence is borrowing constraints. In order to avoid a failure of Ricardian Equivalence by design, our model has no borrowing constraints. Implicit borrowing constraints, such as debt aversion (see Meissner (2016)), might have a similar effect. To rule out these effects, we endow subjects with a positive level of wealth at the beginning of the experiment.

\(^9\)CARA utility was chosen because this class of utility functions is defined in the negative domain. Why this is of importance will be explained later in this section. Using CARA preferences we connect to Caballero (1990, 1991) and other studies on experimental life cycle consumption/savings problems that also make use of CARA utility. See, for instance, Carbone and Hey (2004).
that complies with the rules of the laboratory.\textsuperscript{10} Note that optimal consumption is not very sensitive to variations of $\theta$ around our parameter choice.

The subjects’ objective is to choose consumption in every period to maximise the expected utility of lifetime consumption. The decision problem subjects face at any period $t$ can be written as:

$$\max_{c_t} \mathbb{E}_t \sum_{j=0}^{T-t} u(c_{t+j})$$

s.t. $c_t + a_{t+1} + \tau_t = w_t,$

$$a_1 = 1000, \ a_T = 0,$$

$$\sum_{t=1}^{T} \tau_t = \theta.$$ \hfill (1)

With CARA utility, this optimisation problem can be solved analytically (Caballero (1990, 1991)). Optimal consumption in period $t$ is equal to:\textsuperscript{11}

$$c^*_t(w_t) = \frac{1}{T-t+1} [w_t + (T-t) y_p - \mathcal{T}_t - \Gamma_t(\theta \sigma_y)].$$ \hfill (5)

$$\Gamma_t(\theta \sigma_y) = \sum_{j=0}^{T-t} \sum_{i=1}^{j} \frac{1}{\theta} \log \cosh \left( \frac{\theta \sigma_y}{T-t+1-i} \right).$$ \hfill (6)

$$\mathcal{T}_t = \sum_{j=0}^{T-t} \tau_{t+j} = \vartheta - \sum_{j=1}^{t-1} \tau_j.$$ \hfill (7)

In equation (5), $y_p$ denotes permanent income, which is equal to the mean of the income process, i.e. 185. $\sigma_y = 65$ is one standard deviation of the income process. Equation (6) is the term for precautionary saving.

\textsuperscript{10}See Section 2.2 and Online Appendix D.

\textsuperscript{11}See Online Appendix A for the derivation of optimal consumption.
Note that with respect to tax payments, optimal consumption only depends on the *sum* of current and all future tax payments $\mathcal{T}_t$. Therefore, a tax cut in period $t$ will not affect current optimal consumption. This is because any tax cut must be followed by a later increase in taxes of the same magnitude to permit the government intertemporal budget constraint to hold. In the period after a tax cut, wealth will be higher compared to the same situation without a tax cut in the previous period. This higher wealth, in turn, is offset by the sum of current and future tax payments $\mathcal{T}_t$ which increases by the same amount, leaving optimal consumption unchanged. This implies that the size and order of each of the single lump sum tax payments $\tau = (\tau_1, \tau_2, ..., \tau_T)$ plays no role with respect to optimal consumption, as long as the sum of tax payments over the life cycle is kept constant. This is the definition of Ricardian Equivalence in our experimental environment.

In order to test Ricardian Equivalence, we vary the temporal structure of tax payments, while keeping the sum of taxes to be paid over the experimental life cycle constant. Since optimal consumption is not affected by this variation, subjects have no incentive to react to tax cuts or increases and we can directly compare consumption decisions under different tax schemes.

### 2.1 Treatments

The basic idea of a Ricardian experiment in our framework is a tax cut in early periods of the experimental life cycle that is financed by a tax increase in later periods (Seater, 1993). To isolate the effect of Ricardian taxation we first run a control treatment in which tax payments are kept constant at 120 in all periods ($\vartheta = 3000$). This treatment will be compared to treatments that resemble a Ricardian tax scheme specified in more detail below.

A potential concern in our experiment is that Ricardian taxation may influence the difficulty to smooth consumption. Consider the following two-period example:
in each period income can take on the values 0 and 10 with equal probability. Suppose the income realisations \( y = \{0, 10\} \) are observed in periods 1 and 2, respectively. If the government introduces a tax scheme \( \tau^1 = \{-5, 5\} \), net income becomes \( y^{net} = y - \tau = \{5, 5\} \). In this case smoothing consumption may appear to be easier with taxation than without taxation, because taxation smooths (net) income. On the other hand, if the government decides to do the opposite and asks for a tax scheme \( \tau^2 = \{5, -5\} \), net income equals \( y^n = \{-5, 15\} \) and smoothing consumption might appear more difficult with taxation than without taxation. Of course, taxation does not influence optimal consumption since lifetime income remains unchanged. In particular, the uncertainty of net income is not changed because taxation is deterministic.

In our experiment, differences in behaviour between the Control and the Ricardian treatment could arise from the increased level of difficulty to smooth consumption. It would be misleading to interpret this observation as evidence against Ricardian Equivalence.

To account for this, we design two Ricardian treatments that differ with respect to the difficulty to smooth consumption. This enables us to distinguish the effect of Ricardian taxation from the difficulty of smoothing consumption.

In the first Ricardian treatment (Ricardian 1) tax cuts in the beginning of each round are only given when subjects observe a low (i.e. \( y_t = 120 \)) income realisation (see Table 1). Analogously, tax increases in the later periods of the experiments are only implemented when subjects observe a high (i.e. \( y_t = 250 \)) income realisation. If subjects react to changes in net income, this treatment should be easier to play than the Control treatment, because this taxing scheme essentially smooths net income.

In the second Ricardian treatment (Ricardian 2) tax cuts in the beginning of each round are only received when subjects observe a high income realisation. Tax increases in later periods are only implemented when subjects observe a low income
realisation. This makes net income less smooth and therefore may make it harder for subjects to smooth consumption. Table 1 shows the different tax schemes for one exemplary realisation of the income stream.

To ensure comparability between treatments, subjects in treatments Control, Ricardian 1 and 2 experience the same realisation of the income process, i.e. in any period and round during the experiment, subjects in these treatments receive the same (gross) income. Income realisations differ between rounds, to increase the robustness of our findings by ensuring that observed behaviour is not merely an artefact of one particular realisation of the income process. The timing of the incidence of the tax rates is unknown to subjects in these treatments, and varies with the stochastic income process. However, this does not introduce additional uncertainty because, as shown above, only the sum of taxes over one life cycle is relevant for optimal consumption. This sum is deterministic and kept constant across treatments.\(^{12}\)

To account for the possibility that subjects may nevertheless experience subjective uncertainty about the tax payments, which may affect their behaviour, we introduce an additional control treatment.\(^{13}\) In this treatment (Ricardian 3) the path of all future tax payments is known to subjects. Subjects are informed in the instructions that in periods 2, 4, and 6, taxes will be cut to 0. Taxes are announced to increase to 240 in periods 18, 20, and 22. Since the incidence of the tax payments is now fixed, using the same income realisations as in the previous three treatments may lead to a systematic difference in difficulty across the eight rounds. To prevent this, the

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\(^{12}\)One question in the quiz about the instructions aimed to test if this was understood by subjects (see Online Appendix E, paragraph “Taxes”). About 90% of subjects answered this question correctly, and most of the remaining 10% did choose not answer this question (there was no check if all subjects answered all questions).

\(^{13}\)This treatment is motivated by the finding in Geiger et al. (2016) that subjects do only dissave enough if the future tax path is shown to them. The results in Luhan et al. (2014) and Geiger et al. (2016) are however inconclusive about the consumption response to known future changes.
<table>
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<th>Net Income</th>
<th>Ricardian 1 Taxes</th>
<th>Net Income</th>
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$E[(y - \mu_y)^2]$ | 4,225 | 4,225 | 4,225 | 4,225 |

Source: One exemplary realization of the income stream of own experimental design.
income process is drawn individually for each subject in each round in this treatment. Therefore, a direct comparison across treatments is only possible for the treatments Control, Ricardian 1, and Ricardian 2. The regression analysis in Section 3.2 allows to compare behaviour across all four treatments conditional on income.

2.2 Experimental Procedures

The experiment was programmed and conducted with the software z-Tree (Fischbacher (2007)). The experimental software is an adapted version of the software used in Meissner (2016).\textsuperscript{14} In the instructions, consumption was explained to the subjects as buying “points” by spending the experimental currency “Taler”, in which income was denoted (see Online Appendix D). The experimental currency was converted to points by the utility function specified above. Subjects were informed about the exact form of the utility function. Furthermore, they were given a graph of the function and a table with relevant function values. The advantage of framing consumption as buying points is that negative consumption can be explained as selling points in return for experimental currency.

At the beginning of the experiment, subjects were given time to read the instructions, which were then read aloud by the experimenter. After this, subjects completed a quiz (see Online Appendix E) about the content of the instructions. The correct answers to all questions were then read aloud before subjects started the actual experiment.

In each period of the experiment, subjects were asked to input consumption decisions in an interface that displayed period income, savings from the last period, wealth, and taxes. The interface showed the history of all previous decisions and relevant values, such as savings, wealth, taxes, the sum of taxes paid so far, and

\textsuperscript{14}A screenshot of the experimental interface is provided in Online Appendix D.
the number of purchased points and accumulated points. Before a consumption decision was submitted, subjects were informed about how it would translate into points and the amount of savings that would be available in the next period. After this information was displayed, subjects had the opportunity to start over; that is, they could specify a different level of consumption and check its implications. In the final period of each life cycle, the program automatically spent that period’s wealth minus taxes as consumption.\textsuperscript{15} Then, subjects were informed on a separate screen about the amount of points they purchased during the round. At the end of the experiment, two of the eight experimental life cycles were randomly chosen to be payoff relevant. After the actual experiment, subjects were asked to fill out a questionnaire that contained incentivised lottery choices, which assessed individual risk aversion.

Subjects’ payoffs were determined by a pre-announced linear function of the amount of points purchased in the two relevant rounds. Subjects received a show-up fee of 5 Euro and earned 17.79 Euro on average. The minimum final earning including monetary incentives for elicitation of risk preferences was 5 Euro, the maximum 56.3 Euro, and the standard deviation was 10.18 Euro.

The experiment was conducted at the laboratory of the Technical University of Berlin. Subjects were recruited using ORSEE (see Greiner (2004)). A total of 176 subjects participated. Most of the subjects were undergraduate students in the field of economics or engineering. About one third of the subjects were female.

3 Data Analysis

To identify the effect that taxation has on consumption, we employ two strategies. First, we directly compare deviations from optimal behaviour across treatments to

\textsuperscript{15}This is a consequence of our final period condition given in (3).
identify treatment effects. Second, we run panel regressions to measure the effect of taxes on the deviation from optimal consumption.

### 3.1 Deviations from Optimal Behaviour

As a first step in analysing our experimental data, we examine deviations from optimal behaviour.\(^{16}\) Since subjects in the treatments Control, Ricardian 1, and 2 observe the same income realisations throughout the experiment, we can directly compare deviations from optimal consumption across treatments and rounds.\(^{17}\) Deviations from optimal consumption can be assessed with the following measure (see Ballinger et al. (2003)):

\[
m_1 = \sum_{t=1}^{T} |c^*_t(w_t) - c_t|, \tag{8}
\]

where \(c^*_t(w_t)\) is conditionally optimal consumption (depending on current wealth \(w_t\)), and \(c_t\) is observed consumption in period \(t\). This measure is the sum of absolute deviations from conditionally optimal consumption for one subject and over one experimental life cycle. Indices for subjects and rounds are dropped to facilitate legibility.

In order to compare deviations from unconditionally optimal consumption, we also calculate the following measure:

\[
m_2 = \sum_{t=1}^{T} [u(c^*_t(w_t^*)) - u(c_t)], \tag{9}
\]

\(^{16}\)Note that the intertemporal budget constraint implies that total consumption is the same for each subject in a given round and depends only on the realization of net income plus initial endowment, i.e. \(\sum_{t=1}^{T} c_t = \sum_{t=1}^{T} y_t - \sum_{t=1}^{T} \tau_t + a_1\).

\(^{17}\)Recall that this is not true for subjects in the treatment Ricardian 3. For this reason, the analysis in this section excludes observations from that treatment.
where $c^*_t(w^*_t)$ denotes unconditionally optimal consumption at period $t$ as a function of optimal period wealth $w^*_t$. This measure can be interpreted as the utility loss that results from suboptimal consumption. With this measure we can assess the effect of Ricardian taxation on welfare in our experimental environment.

Figure 1 shows the medians of the measures $m_1$ and $m_2$ by treatments and rounds. At first glance subjects appear to perform best in the Control treatment. Subjects in the Ricardian 2 treatment have higher deviations from optimal consumption and a higher utility loss compared to subjects in the Control treatment. Subjects in the Ricardian 1 treatment seem to be somewhere between the Control and Ricardian 2 treatments.

This intuition can be confirmed by examining the total effect; that is, the measures $m_1$ and $m_2$ averaged for each subject over the eight rounds of the experiment. For both measures, subjects perform significantly better in the Control treatment compared to subjects in Ricardian 1 (p-values from a Mann-Whitney U-test are pro-

---

18 Additionally, the Online Appendix contains Figure C.1, in which welfare loss is denominated in terms of money that subjects loose by behaving suboptimally.
Table 2: Medians of the Measures $m_1$ and $m_2$ by Treatments and Rounds.

<table>
<thead>
<tr>
<th>Round</th>
<th>Median</th>
<th>Total</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>m1 Ctrl</td>
<td>759.75</td>
<td>1192.37</td>
<td>912.01</td>
<td>712.87</td>
<td>752.35</td>
<td>754.05</td>
<td>671.31</td>
<td>648.53</td>
<td>608.10</td>
<td></td>
</tr>
<tr>
<td>m1 R1</td>
<td>838.66</td>
<td>1355.96</td>
<td>1035.61</td>
<td>853.42</td>
<td>675.27</td>
<td>829.30</td>
<td>755.12</td>
<td>611.36</td>
<td>671.83</td>
<td></td>
</tr>
<tr>
<td>m1 R2</td>
<td>949.25</td>
<td>1429.39</td>
<td>1235.89</td>
<td>976.59</td>
<td>990.56</td>
<td>877.47</td>
<td>841.66</td>
<td>739.42</td>
<td>687.04</td>
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</tr>
<tr>
<td></td>
<td>p-Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>R1-Ctrl</td>
<td>0.02</td>
<td>0.03</td>
<td>0.51</td>
<td>0.24</td>
<td>0.10</td>
<td>0.43</td>
<td>0.37</td>
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<tr>
<td>R2-Ctrl</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.08</td>
<td>0.03</td>
<td>0.32</td>
<td>0.30</td>
<td>0.08</td>
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<tr>
<td>R1-R2</td>
<td>0.00</td>
<td>0.09</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.66</td>
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<tr>
<td>m2 Ctrl</td>
<td>350.35</td>
<td>631.76</td>
<td>355.19</td>
<td>454.94</td>
<td>267.78</td>
<td>147.19</td>
<td>405.13</td>
<td>248.38</td>
<td>281.20</td>
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<tr>
<td>m2 R1</td>
<td>381.70</td>
<td>862.93</td>
<td>483.72</td>
<td>549.26</td>
<td>271.92</td>
<td>213.33</td>
<td>344.64</td>
<td>232.34</td>
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<tr>
<td>m2 R2</td>
<td>497.61</td>
<td>928.82</td>
<td>737.49</td>
<td>604.52</td>
<td>453.11</td>
<td>440.39</td>
<td>408.98</td>
<td>321.48</td>
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<tr>
<td>R1-Ctrl</td>
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<td>0.00</td>
<td>0.46</td>
<td>0.12</td>
<td>0.01</td>
<td>0.14</td>
<td>0.06</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>R2-Ctrl</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.74</td>
<td>0.00</td>
<td>0.68</td>
<td>0.04</td>
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</tr>
<tr>
<td>R1-R2</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.17</td>
<td></td>
</tr>
</tbody>
</table>

Notes: P-values of Mann-Whitney U-tests.

vided in Table 2). Subjects in the Ricardian 2 treatment have significantly higher absolute deviations from optimal consumption and higher utility loss compared to both Ricardian 1 and Control (see column Total in Table 2).

Examining the differences across treatments in the specific rounds reveals that this relationship is significant for many, but not all rounds. Absolute differences from optimal consumption (measure $m_1$) are significantly higher in Ricardian 2 compared to Control in six of eight rounds. When comparing $m_1$ between Ricardian 1 and Control, $m_1$ is significantly higher in Ricardian 1 compared to Control in three out of eight rounds. Comparing $m_1$ between Ricardian 1 and Ricardian 2 reveals that absolute deviations from optimal consumption are significantly higher in Ricardian 2
in all but two rounds. Overall this finding confirms the above intuition, though the evidence is not very strong in comparing Ricardian 1 and Control at the round level. In Table C.1 in the Online Appendix we replicate these results using regression techniques.\(^{19}\)

Comparing measure \(m_2\) (utility loss) at the round level across the three different treatments yields similar results. Utility loss is significantly higher in Ricardian 2 than in Control in all but rounds four and six. Measure 2 is significantly higher in Ricardian 1 compared to Control in four out of eight rounds. With respect to the Ricardian treatments, utility loss in Ricardian 2 is significantly higher than in Ricardian 1 in seven of the eight rounds.

Deviations from optimal consumption as well as utility loss appear to decline over the eight rounds of the experiment. This supports the idea that subjects learn to improve their consumption decisions by repeating the experiment. We investigate learning behaviour in more detail in Section 3.3.

In summary, subjects in treatments with Ricardian taxation have higher deviations from optimal consumption and a higher utility loss than subjects in the Control treatment. Moreover, subjects with a net income stream that is difficult to smooth (Ricardian 2) appear to perform worse than subjects with a net income stream that is easy to smooth. These findings imply that subjects react to both difficulty to smooth consumption and Ricardian taxation. However, the finding that subjects in Ricardian 1 appear to perform worse than subjects in the Control treatment suggests that the effect of Ricardian taxation outweighs that of the decreased difficulty

\(^{19}\) We report regression results using treatment dummies \(d_{R1}\) and \(d_{R2}\), round dummies \(d_{r,1}\) to \(d_{r,8}\), and their interactions as regressors and aggregate absolute deviations \(m_1\) as dependent variable. This regression reproduces the results from the nonparametric analysis in Table 2. The constant is statistically not different from the corresponding median value of the Control treatment for round 1 in Table 2. The coefficients on the treatment dummies are similarly not different from the respective median value for round 1. The interaction terms show how these medians change over rounds and treatments.
to smooth consumption. One mechanism that would result in such a finding is that subjects do not internalise the government budget constraint but instead treat a tax benefit as additional wealth.

3.2 Panel Regression

In order to assess the magnitude of the effect that Ricardian taxation has on consumption, we run structural panel regressions.

Our baseline specification derived from equation (5) is

\[
c_{it} = \beta_1 y_{it} + \beta_2 a_{it} + \beta_3 (T - t) \bar{y}_p - \beta_4 \bar{\Gamma}_{it} - \beta_5 \bar{\Gamma}_{ts} (\theta \sigma_y),
\]

for all subjects \(i = 1, \ldots, 176\), periods \(t = 1, \ldots, 25\), and rounds \(r = 1, \ldots, 8\) where \(\bar{\Gamma} = \frac{1}{(T - t + 1)} \Gamma\), and \(\Gamma\) represents the variables of equation (5).\(^{20}\) We transform the regressors that are derived from the theoretical consumption function in this way to account for the time dependency of optimal consumption. Moreover, this simplifies the interpretation of the corresponding coefficients. If subjects behave optimally, or deviate randomly from optimal consumption, e.g. due to calculation errors, the estimated coefficients \(\beta_1\) to \(\beta_5\) should be equal to one.

**Hypothesis 1:** \(\beta_1\) to \(\beta_5\) are not statistically different from one.

If we reject this hypothesis, subjects deviate systematically from optimal consumption. In equation (11), we extend our baseline specification to account for tax effects by including dummy variables indicating a tax rebate \(d_{0,tx}\) and a tax increase

\(^{20}\)The total of 176 subjects includes 44 subjects in treatment Ricardian 1, 47 in Ricardian 2, 43 in Ricardian 3 and 42 in Control.
Moreover, we control for treatment using treatment dummies $(dR_1, dR_2, dR_3)$ and subject characteristics $X_i$ such as risk preference, gender, and subject of academic study.\textsuperscript{21} Finally, we account for round effects and include a constant, period, and period squared. The latter two variables should capture any time trend that is beyond the theoretical.

\begin{equation}
    c_{itr} = \beta_1 \bar{y}_{itr} + \beta_2 \bar{a}_{itr} + \beta_3 (T - t) \bar{y}_p - \beta_4 \bar{f}_{itr} - \beta_5 \bar{f}_{tr}(\theta \sigma_y) + \beta_{0,tx} d_{0,tx} + \beta_{240,tx} d_{240,tx} + \beta_6 dR_{1i} + \beta_7 dR_{2i} + \beta_8 dR_{3i} + \beta_9 X_i + \sum_{k=1}^{8} \beta_{r,k} d_{r,k} + \beta_{10} t + \beta_{11} t^2 + \text{constant}.
\end{equation}

Since all these additional regressors do not show up as variables in the optimal consumption function, the corresponding coefficients should not be significantly different from zero if subjects behave optimally or deviate randomly from optimal consumption.

**Hypothesis 2:** $\beta_{0,tx}$ and $\beta_{240,tx}$, $\beta_{r,1}$ to $\beta_{r,8}$, and $\beta_6$ to $\beta_{11}$ are not statistically different from zero.

If we reject this hypothesis, subjects deviate systematically from optimal consumption. Table 3 shows what factors are associated with observed consumption ($c_{itr}$).\textsuperscript{22} The first specification reported in this table is the baseline model (equation 10) plus a constant which should be equal to zero according to the theory. The

\textsuperscript{21}Subjects who are not students, i.e. unemployed or employees, are subsumed under *other* in Table 3.

\textsuperscript{22}We suppress henceforth subject and round indices to facilitate legibility.
second specification refers to the extend model in equation (11). Individual specific characteristics, such as ability to use computer software, could bias our estimates. To obtain consistent results, we estimate a fixed effects (FE) specification that is presented along with the OLS specifications. All specifications are estimated with robust standard errors clustered at the subject level. In the following analysis we will focus on the more robust FE estimation, while acknowledging any substantial differences in the different specifications. Recall that if subjects behave optimally or deviate randomly from optimal consumption, the estimated coefficients $\beta_1$ to $\beta_5$ should equal one.

For $\beta_1$, the data reject this hypothesis. Table 3 shows that the coefficient for current income is significantly higher than one. This implies that individuals react to changes in current income more strongly than optimal. While this finding conflicts with the theory, it is consistent with the notion of excess sensitivity from the empirical literature.\(^{23}\) Subjects consistently do not only consume too much out of current income, but also out of expected income. The estimate for the coefficient on $(T - t)\tilde{y}_p$ is of similar size, however, only statistically different from one in the baseline specification. Subjects do not seem to have correct intuition about what the levels of current and expected income imply for their decision problem, or they simply overreact to income changes.

The coefficient on savings indicates that subjects do not spend enough out of wealth since the estimate is statistically smaller than one throughout. This could again stem from difficulties in assessing magnitudes, or it could reflect a social norm that deems parsimony as a virtue.

The amount of future due taxes might not have been assessed correctly either.

\(^{23}\)See e.g. Flavin (1981); Hall and Mishkin (1982); Souleles (1999); Shea (1995); Parker (1999). Several explanations for excess sensitivity are debated in the literature; in particular, myopic behaviour, liquidity constraints, and buffer-stock saving.
The coefficient in the extended specifications is about one third of what theory predicts, while the estimate in the baseline specification is quite imprecise with a 95% confidence interval that includes both 0.57 and 1.57. A ceteris paribus interpretation of the much more precise FE estimate implies that one Taler less (the variable is defined as -1 times the original variable) of future taxes to be paid increases spending by 0.307 Taler instead of one.

The impact of precautionary saving on consumption should be captured by the coefficient on $\tilde{\Gamma}(\theta \sigma_y)$. The estimated coefficient is approximately twice as high as theory would predict in the extended specification, but not statistically different from one in both extended and the baseline specifications.\(^{24}\) Note also, that the coefficient on the period ($t$) is significantly negative. The regressors $t$ and $t^2$ were included to capture any time trend beyond the theoretical. The negative coefficient on $t$ implies that subjects consume too much in early periods compared to later periods. This is consistent with other intertemporal consumption experiments, where overconsumption is regularly found.\(^{25}\)

The coefficients of our particular interest are $\beta_{0.tx}$ and $\beta_{240.tx}$ because they indicate how subjects react to a tax rebate ($\tau_t = 0$) and a tax increase ($\tau_t = 240$) respectively.

In the FE specification, the estimated coefficient $\beta_{0.tx}$ is $25.26$ (p-value: $< 0.01$). This implies that a tax rebate of 120 Taler is associated with an increase in consumption of 25.26 Taler, or 21% of the tax rebate. In turn, the estimated coefficient corresponding to a tax increase ($\beta_{240.tx}$) is $-30.02$ (p-value: $< 0.01$), implying that an increase in taxes of 120 Taler is associated with a decrease in consumption of 30.02 Taler, or about 25% of the tax increase.

\(^{24}\)See, e.g., Fossen and Rostam-Afschar (2013) who show that it is difficult to measure the importance of precautionary saving and to disentangle it from entrepreneurial saving with survey data.

\(^{25}\)See Duffy (2012) for an excellent survey on intertemporal consumption experiments.
These results give account of the average effect of taxation in all Ricardian treatments. However, we are also interested in whether reactions to taxation differ by treatment. We can identify the effects of Ricardian taxation separately by including interaction terms of $d_{0,tx}$ and $d_{240,tx}$, with binary variables indicating treatment Ricardian 1, Ricardian 2 and Ricardian 3 respectively.

In treatment Ricardian 1, the estimated coefficient corresponding to a tax rebate is 15.52 (p-value = 0.017) and the coefficient corresponding to a tax increase is $-36.2$ (p-value < 0.01).\textsuperscript{26} In treatment Ricardian 2 the coefficient corresponding to a tax rebate is 27.14 (p-value < 0.01) and that corresponding to a tax increase is $-20.24$ (p-value < 0.01).\textsuperscript{26} Finally, in treatment Ricardian 3 the coefficient corresponding to a tax rebate is 27.03 (p-value < 0.01) and that corresponding to a tax increase is $-29.45$ (p-value < 0.01).\textsuperscript{26} These estimates indicate that subjects react to taxes in a similar way in all treatments. The coefficients associated with a tax rebate turn out not to be significantly different in the treatments Ricardian 1, Ricardian 2, and Ricardian 3 in mutual and joint tests. A significant difference (mutual p-value = 0.03, joint p-value = 0.09) is observed only between the coefficients corresponding to a tax increase of Ricardian 1 and Ricardian 2.\textsuperscript{27}

Overall, our results suggest that taxes have a significant and strong effect on consumption. This is in stark contrast with the theoretical predictions, and thus we conclude that the Ricardian proposition is rejected by the experimental data. An early tax benefit causes a significant increase in consumption on average. The corresponding later increase in taxation causes a significant decrease in consumption on average.

\textsuperscript{26}Not reported in Table 3.

\textsuperscript{27}Table C.2 in the Online Appendix shows the FE regressions for the Control treatment and each Ricardian treatment in comparison to the Control treatment. The coefficients for tax rebates and increases show a similar pattern though they change somewhat due to smaller sample size.
Table 3: Panel Regressions on Observed Consumption.

<table>
<thead>
<tr>
<th></th>
<th>Baseline OLS</th>
<th>Extended OLS</th>
<th>FE</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \tilde{y} )</td>
<td>1.135** (17.77)</td>
<td>1.160** (18.17)</td>
<td>1.187*** (22.56)</td>
</tr>
<tr>
<td>( \tilde{a} )</td>
<td>0.642*** (196.30)</td>
<td>0.655*** (87.40)</td>
<td>0.780*** (29.06)</td>
</tr>
<tr>
<td>((T - t)\tilde{y}_p)</td>
<td>1.165* (13.78)</td>
<td>1.130 (7.32)</td>
<td>1.204 (6.92)</td>
</tr>
<tr>
<td>( \tilde{y} )</td>
<td>1.065 (4.20)</td>
<td>0.272*** (4.47)</td>
<td>0.307*** (4.49)</td>
</tr>
<tr>
<td>( \tilde{f}(\theta\sigma) )</td>
<td>3.318 (1.76)</td>
<td>2.017 (0.58)</td>
<td>2.180 (0.63)</td>
</tr>
</tbody>
</table>

Tax dummies (base: 120):
- \( d_{0.tx} \)
- \( d_{240.tx} \)
- \( t \)
- \( t^2 \)

<table>
<thead>
<tr>
<th></th>
<th>Baseline OLS</th>
<th>Extended OLS</th>
<th>FE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23.50*** (6.05)</td>
<td>25.26*** (5.44)</td>
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</tr>
<tr>
<td></td>
<td>-28.71*** (-7.87)</td>
<td>-30.02*** (-6.69)</td>
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<tr>
<td></td>
<td>-3.038*** (-3.26)</td>
<td>-3.037*** (-3.25)</td>
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</tr>
<tr>
<td></td>
<td>0.101 (1.57)</td>
<td>0.104 (1.64)</td>
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</table>

Treatment (base: Control):
- \( dR1 \)
- \( dR2 \)
- \( dR3 \)

<table>
<thead>
<tr>
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<tbody>
<tr>
<td></td>
<td>-25.16* (-1.89)</td>
<td></td>
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<tr>
<td></td>
<td>-21.41* (-1.96)</td>
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<tr>
<td></td>
<td>-33.92** (-2.16)</td>
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</table>

Round dummies (base: round 1):
- \( d_{r.2} \)
- \( d_{r.3} \)
- \( d_{r.4} \)
- \( d_{r.5} \)
- \( d_{r.6} \)
- \( d_{r.7} \)
- \( d_{r.8} \)

<table>
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<tr>
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<th>Baseline OLS</th>
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<tr>
<td></td>
<td>-5.153 (-0.94)</td>
<td>-6.389 (-1.00)</td>
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<tr>
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<td>-4.073 (-0.76)</td>
<td>-3.586 (-0.56)</td>
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<td>-1.573 (-0.27)</td>
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<td>-3.283 (-0.59)</td>
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<td>-3.489 (-0.63)</td>
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Risk aversion (base: low):
- high
- medium

<table>
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<th>Extended OLS</th>
<th>FE</th>
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<tr>
<td></td>
<td>-23.92* (-1.82)</td>
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</tr>
<tr>
<td></td>
<td>-16.07 (-1.36)</td>
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</table>

Gender (base: male):
- female

<table>
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<th>Extended OLS</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>24.80* (1.95)</td>
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</table>

Subject (base: economics):
- engineering
- otherscience
- other

<table>
<thead>
<tr>
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<th>Extended OLS</th>
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<tbody>
<tr>
<td></td>
<td>-4.834 (-0.58)</td>
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<tr>
<td></td>
<td>1.692 (0.20)</td>
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<tr>
<td></td>
<td>-22.96 (-1.56)</td>
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</table>

<table>
<thead>
<tr>
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<th>Baseline OLS</th>
<th>Extended OLS</th>
<th>FE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>20.64 (0.81)</td>
<td>-40.32 (-1.42)</td>
<td>-85.14*** (-5.37)</td>
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<tr>
<td>Adjusted ( R^2 )</td>
<td>0.498</td>
<td>0.509</td>
<td>0.603</td>
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<tr>
<td>Overall ( R^2 )</td>
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</tbody>
</table>

Notes: The dependent variable is observed consumption \((c_{itx})\). T-statistics based on cluster robust (subject level) standard errors are in parentheses. T-statistics and significance levels of the first five regressors refer to tests of the \(H_1\) (see text) that the respective variable is equal to 1, significance levels are \* \(p < 0.10\), \*\* \(p < 0.05\), \*\*\* \(p < 0.01\). All other t statistics and significance levels refer to tests of the \(H_2\) (see text) for which the respective variable is equal to zero; significance levels are \* \(p < 0.10\), \*\* \(p < 0.05\), \*\*\* \(p < 0.01\).
Our findings are based on pooling all subjects. However, there appears to be some heterogeneity in our experimental data that cannot be controlled for, even with a fixed effects specification. Generally, this occurs when subjects employ different strategies to choose consumption. Therefore, we run individual OLS regressions for each subject, using the same specification as above to identify the share of subjects that behaves in accordance with Ricardian Equivalence. This allows to estimate different coefficients for each subject and thus accounts for different strategies. We classify the subjects’ behaviour as follows: if either the coefficient associated with a tax benefit ($\beta_{0,tx}$), the coefficient associated with a tax increase ($\beta_{240,tx}$), or both are significantly different from zero at the 5% level, a subject’s behaviour is inconsistent with Ricardian Equivalence. In this conservative way, we find that the behaviour of approximately 56% of our subjects in the Ricardian treatments can be classified as being not consistent with Ricardian Equivalence. If we only require the coefficient associated with a tax benefit ($\beta_{0,tx}$) not to be statistically different from zero at the 5% level, about 34% of our subjects are classified as being not consistent with Ricardian Equivalence.

### 3.3 Learning

It has been shown in many experiments on intertemporal optimisation that subjects tend to improve their decision-making towards optimality when playing the experiment repeatedly. This is typically interpreted as evidence for learning. Figure 1 of Section 3.1 suggest that this may also be the case in our experiment.

In order to formally test whether subjects improve their consumption decisions,

---

28 Here we abstract from learning effects. We investigate the different behavioural strategies with a focus on learning in Subsection 3.4.

29 See for instance Ballinger et al. (2003), Carbone and Hey (2004), Brown et al. (2009), Meissner (2016).
Table 4: Change of Deviations from Optimal Consumption over Rounds

<table>
<thead>
<tr>
<th>Round</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median $m_1^1 - m_r^r$</td>
<td>147.09</td>
<td>262.61</td>
<td>244.56</td>
<td>294.00</td>
<td>371.32</td>
<td>355.30</td>
<td>415.85</td>
</tr>
<tr>
<td>p-value</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Median $m_r^{r-1} - m_1^r$</td>
<td>147.09</td>
<td>81.96</td>
<td>31.17</td>
<td>48.32</td>
<td>17.46</td>
<td>42.66</td>
<td>23.10</td>
</tr>
<tr>
<td>p-value</td>
<td>0.00</td>
<td>0.00</td>
<td>0.18</td>
<td>0.06</td>
<td>0.14</td>
<td>0.02</td>
<td>0.26</td>
</tr>
</tbody>
</table>

*Notes:* Median differences in $m_1$ between consecutive rounds and to the first round. P-values of Wilcoxon matched-pairs signed-ranks test in parentheses. The null hypothesis is that both distributions are the same.

we analyse within subject differences of absolute deviations from optimal consumption (Measure $m_1$) across rounds. Table 4 contains the median of within subject differences in absolute deviations from optimal consumption between round $r$ and the first round ($m_1^1 - m_1^r$), as well as the median difference in absolute deviations from optimal consumption between two consecutive rounds ($m_r^{r-1} - m_1^r$). There is a significant reduction in deviations from optimal consumption between rounds one and two, two and three, six and seven, and a marginally significant reduction between rounds four and five (p-value = 0.06). However, all rounds show significant improvement of consumption decisions in comparison to the first round. Hence subjects seem to be able to improve their consumption decisions with repetition of the experiment.

The main goal of this paper is to test if subjects learn to behave according to the prediction of the Ricardian proposition. That is whether they learn not to react to tax cuts and tax increases with their consumption choices. To answer this question, we ran two additional specifications of the panel regressions introduced in Section 3.2. In specification FE (1) in Table 5 we include interaction terms of the tax dummy for a tax cut and a tax increase with a dummy indicating each round,
respectively. This allows to see whether there is a reduction in the reaction to a tax cut or tax increase, relative to the baseline.

**Hypothesis 3:** \( \beta_0.\text{tx} \times r^2 \) to \( \beta_0.\text{tx} \times r^8 \), \( \beta_{240.\text{tx}} \times r^2 \), \( \beta_{240.\text{tx}} \times r^8 \), \( \beta_0.\text{tx} \), and \( \beta_{240.\text{tx}} \) are not statistically different from zero.

If we reject one of these hypotheses, consumption choices are not made in accordance with Ricardian Equivalence. The partial effect of a tax cut (increase) on consumption in round 1 (when all round dummies are zero) is significantly positive (negative). Significantly negative (positive) interaction terms imply that a tax cut (increase) yields a lower effect on consumption in the particular round. Only the coefficient of a tax increase interacted with round eight is significant at the 10% level, while the absolute magnitude of the coefficients increases with round.

Still, reductions in the reaction to tax cuts and tax increases do not imply that reactions disappear entirely. This is clearer in specification FE (2) in which we exclude as regressors the dummies for tax cuts and tax increases, respectively. The coefficients of the interactions of the dummies for a tax-cut and a tax-increase with round dummies may then be interpreted as the absolute effect taxation has on consumption in each particular round.

The absolute values of the coefficients on these interactions are decreasing over rounds. However, all coefficients are highly significantly different from zero. This implies that taxation affects consumption in all eight rounds.

Summing up, we observe that subjects generally improve their consumption decisions towards optimality when repeating the experiment. We find some evidence that the extent to which subjects react to tax increases decreases with rounds. However, even after eight rounds of learning, tax cuts and increases have a significant
Table 5: Learning Effects in Panel Regression on Observed Consumption.

<table>
<thead>
<tr>
<th></th>
<th>FE (1)</th>
<th>FE (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \tilde{y} )</td>
<td>1.185*** (22.66)</td>
<td>1.192*** (22.49)</td>
</tr>
<tr>
<td>( \tilde{a} )</td>
<td>0.781*** (29.10)</td>
<td>0.780*** (29.13)</td>
</tr>
<tr>
<td>( (T - t)\tilde{y}_p )</td>
<td>1.203 (6.97)</td>
<td>1.194 (6.93)</td>
</tr>
<tr>
<td>( \tilde{Y} )</td>
<td>0.296*** (4.34)</td>
<td>0.438*** (6.45)</td>
</tr>
<tr>
<td>( \tilde{\Gamma}(\theta \sigma_y) )</td>
<td>2.201 (0.64)</td>
<td>2.114 (0.61)</td>
</tr>
</tbody>
</table>

Tax dummies (base: 120):
- \( d_{0,tx} \): 30.85*** (3.42)
- \( d_{240,tx} \): -36.75*** (-4.23)

Interaction of tax cut and round (base: round 1, 120):
- \( d_{r,2} \times d_{0,tx} \): 0.406 (0.04)
- \( d_{r,3} \times d_{0,tx} \): -1.541 (-0.16)
- \( d_{r,4} \times d_{0,tx} \): -4.345 (-0.45)
- \( d_{r,5} \times d_{0,tx} \): -8.157 (-0.89)
- \( d_{r,6} \times d_{0,tx} \): -9.872 (-1.05)
- \( d_{r,7} \times d_{0,tx} \): -9.551 (-1.04)
- \( d_{r,8} \times d_{0,tx} \): -11.23 (-1.20)

Interaction of tax increase and round (base: round 1, 120):
- \( d_{r,2} \times d_{240,tx} \): -0.512 (-0.06)
- \( d_{r,3} \times d_{240,tx} \): 5.716 (0.64)
- \( d_{r,4} \times d_{240,tx} \): 4.317 (0.46)
- \( d_{r,5} \times d_{240,tx} \): 4.830 (0.52)
- \( d_{r,6} \times d_{240,tx} \): 11.72 (1.29)
- \( d_{r,7} \times d_{240,tx} \): 9.182 (1.07)
- \( d_{r,8} \times d_{240,tx} \): 16.76* (1.90)

Round dummies (base: round 1):
- \( d_{r,2} \): -6.345 (-0.87)
- \( d_{r,3} \): -3.977 (-0.54)
- \( d_{r,4} \): -2.515 (-0.33)
- \( d_{r,5} \): -0.881 (-0.12)
- \( d_{r,6} \): -3.704 (-0.49)
- \( d_{r,7} \): -2.762 (-0.37)
- \( d_{r,8} \): -3.359 (-0.45)

- \( t \): -3.088*** (-3.30)
- \( t^2 \): 0.106* (1.67)
- Constant: -85.99*** (-5.37)

Adjusted \( R^2 \): 0.603
Overall \( R^2 \): 0.498

Notes: The dependent variable is observed consumption (\( c_{it} \)). T-statistics based on cluster robust (subject level) standard errors are in parentheses. T-statistics and significance levels of the first five regressors refer to tests of the \( H_0 \) that the respective variable is equal to 1, significance levels are * \( p < 0.10 \), ** \( p < 0.05 \), *** \( p < 0.01 \). All other t statistics and significance levels refer to tests of the \( H_0 \) for which the respective variable is equal to zero; significance levels are * \( p < 0.10 \), ** \( p < 0.05 \), *** \( p < 0.01 \).
impact (both statistically and economically) on consumption choices. This implies that subjects on average do not learn to comply with the Ricardian Equivalence in the eight repetitions of our experiment.

### 3.4 Rules of Thumb

Even though our experimental environment is highly stylised, finding the optimal solution is a nontrivial task. A natural starting point to model behaviour and analyse learning is therefore the idea that subjects use rules of thumb (e.g. Cochrane, 1989). In this section, we investigate the usage of the following rules of thumb:

1. **σ-zero-approximation** According to this rule, subjects consume as if income uncertainty were zero ($\sigma_y = 0$). That is, the optimal decision rule is approximated by abstracting from precautionary saving. This simplifies equation (5) to

   \[
   c_{t}^{\sigma=0}(w_t) = \frac{1}{T - t + 1} \left[ w_t + (T - t)y_p - T \right].
   \]  

   (12)

   This rule describes behaviour of subjects that are forward looking, i.e. subjects take the number of remaining periods into account, calculate permanent income and the amount of taxes to be paid. Effectively, they calculate consumption as the expected funds available to them in the remaining periods, divided by the number of periods remaining. Since aggregate income uncertainty is relatively small in this experiment, precautionary saving is also relatively small. Therefore, this consumption rule is a rather close approximation of optimal consumption. Moreover, since all tax payments are taken into consideration correctly, agents who follow this rule should not violate Ricardian Equivalence.

2. **Constant consumption** Subjects who behave according to this rule are forward looking because they calculate their (ex-ante) expected net resources and
smooth this value over time. Equation (12) is approximated with information on the initial and final period only by

\[ c_t^{\text{const}} = c_{t+1} = \ldots = c_{T-1} = \frac{1}{T}(a_1 - \vartheta) + y_p = 105. \tag{13} \]

Subjects with this consumption function may be quite far from the optimal solution but it is important to note that this decision rule implies Ricardian Equivalence.

3. Constant fraction of period net income Another potential rule of thumb is consuming a constant fraction of period net income. In our experimental environment, this alone would be a poor consumption rule due to the initial endowment. Therefore, in the rule of thumb specified below, agents smooth their initial endowment over the life-cycle, and consume a constant fraction of their net income on top in each period.

\[ c_t^y = \frac{1}{T}a_1 + \kappa_y [y_t - \tau_t]. \tag{14} \]

Agents who behave according to this rule violate Ricardian equivalence.

4. Constant fraction of period cash on hand With this rule, agents consume a constant fraction of their wealth minus taxes (= cash on hand) in each period. This rule is modelled after the “Keynesian” consumption function and is similar to one of the rules considered in Brown et al. (2009). Agents who behave according to this rule violate Ricardian Equivalence.

\[ c_t^w(w_t) = \kappa_w [w_t - \tau_t]. \tag{15} \]

In addition, we also consider optimal consumption, as specified in equation (5), as one potential consumption rule. For convenience, we report the theoretic predictions regarding Ricardian Equivalence of each considered consumption rule in Table 6.
To match behaviour of our subjects to one of the above consumption rules, we calculate consumption levels predicted by each of the consumption rules. We calculate $\kappa_y$ and $\kappa_w$ using Monte Carlo simulations such that the parameters yield rule specific optimal consumption. In this way, the degrees of freedom identical across all rules, no parameters are left as free parameters. We then calculate the root mean squared error (RMSE) of observed consumption and the prediction of each consumption rule for each subject and each round. The smaller the RMSE, the better a consumption rule describes behaviour. We therefore classify subjects to each of these rules in each round if the respective RMSE is smallest.\(^{30}\)

Figure 2 shows the resulting composition of our sample. The figure displays the percentage of our sample that uses each of the rules, sorted by frequencies in round 8, where most of the subjects should have finished the learning process. If no subject had changed the strategy over rounds, the figure would show 5 areas separated by 4 horizontal lines. This is clearly not the case.

In round one, only about 40% of our subjects reveal behaviour that can be best

\(^{30}\)See e.g. Ballinger et al. (2003), who use the same method to categorise subjects according to different apparent planning horizons. See Figure C.3 in the Online Appendix for the median RMSE separated by types and rounds.
described by optimal consumption or the very close to optimal $\sigma$-zero-approximation. 14% of the subjects appear to follow the constant consumption strategy in this round. Subjects’ behaviour in the first round is most frequently best described by the strategy to consume a constant fraction of wealth (34%). The share of subject whose behaviour is best described by consuming a fraction of net income remains relatively stable over the eight rounds at around 10 to 15%.

The main result with regard to learning behaviour is that, over the course of the eight rounds, the share of subjects who appear to consume optimally or near optimally increases drastically to about 70%. This striking increase is contrasted by the share of subjects who consume a constant amount or a constant fraction of their
wealth. Their share decreases by roughly the same magnitude, to about 20%. This implies that subjects do learn to improve their consumption decisions, by changing their consumption rules over the course of the experiment.

What does this imply for Ricardian Equivalence? In the first round, about 47% follow strategies that violate Ricardian Equivalence (fraction of net income, fraction of cash on hand). In round 8, this fraction is halved; only 24% follow these strategies. This suggests that some subjects learn Ricardian Equivalence, by adjusting their employed consumption rules. This can be confirmed by Table 7, which provides for each round the percentage of subjects who appear to switch their strategy.

The last row in Table 7 reports the total fraction of subjects who appear to switch their strategy over all rounds of the experiment. In the early rounds, the percentage of people who switch strategies is relatively high: about 57% of all subjects choose a different strategy in the second round compared to the first round. This fraction declines over rounds to about 36% in the last round. Considering the individual consumption rules, the striking pattern is that subjects switch in the second round to each of the strategies with roughly the same probability. This changes over rounds. In particular, increasingly more subjects switch to the $\sigma$-zero-approximation

### Table 7: Strategy Evolution.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Unit</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>to $\sigma$-Zero-Approximation</td>
<td>(%)</td>
<td>14</td>
<td>16</td>
<td>14</td>
<td>14</td>
<td>20</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>to Optimal Consumption</td>
<td>(%)</td>
<td>11</td>
<td>19</td>
<td>18</td>
<td>10</td>
<td>17</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>to Constant Consumption</td>
<td>(%)</td>
<td>14</td>
<td>9</td>
<td>10</td>
<td>9</td>
<td>5</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>to Fraction of Cash on Hand</td>
<td>(%)</td>
<td>9</td>
<td>5</td>
<td>8</td>
<td>4</td>
<td>7</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>to Fraction of Net Income</td>
<td>(%)</td>
<td>9</td>
<td>7</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Total Switchers</td>
<td>(%)</td>
<td>57</td>
<td>56</td>
<td>53</td>
<td>41</td>
<td>53</td>
<td>37</td>
<td>36</td>
</tr>
</tbody>
</table>
or the optimal rule. Transitions to rules that violate Ricardian Equivalence decline substantially towards the later rounds.\footnote{31}

An interesting question is now whether the consumption rule that people employ has predictive power regarding whether subjects comply with Ricardian Equivalence or not.

To test this, we divide our sample in each round by the five strategies. We then run our extended specification (Equation (11)) individually for each strategy and round, such that the estimates show the joint effect of learning over time of subjects who stick to a strategy and of those who switch strategies. Therefore, the number of observations varies by round and strategy, as illustrated in Figure 2.\footnote{32}

Since we are interested in learning Ricardian behaviour, we only report the estimated coefficients on the tax cut and the tax increase dummies over different rounds for each strategy.\footnote{33}

The differences in rules reported in Table 8 are as expected: the strategies that are consistent with Ricardian Equivalence have much smaller coefficients on the dummies for tax cuts and increases compared to the strategies that are predicted to violate Ricardian Equivalence.

Moreover, Table 8 provides another piece of evidence that some subjects learn Ricardian Equivalence. Even though the theoretical prediction for the rules \textit{optimal consumption} and \textit{σ-zero-approximation} is that Ricardian Equivalence should hold, most point estimates are significantly positive (negative) for a tax cut (increase).

\footnote{31While Table 7 illustrates what rules subjects switch \textit{to} between rounds, we also report the reverse, i.e. \textit{from} what rules subject switch to other rules, in the Online Appendix: Table C.4 shows that transition to rules that are in accordance with Ricardian Equivalence are mostly higher than transition from these rules. In contrast, for the non-Ricardian rules efflux is almost always greater than influx.}

\footnote{32Note that this split decreases the sample size for each of the individual estimations drastically. Therefore, the results should be interpreted with caution.}

\footnote{33Full estimation results are available on request.}
Over the eight rounds, the magnitudes of the point estimates appear to grow somewhat smaller, though only in few cases significantly. This suggests that subjects learn to react less to tax cuts and increases, but still show small reactions on average.
Table 8: Reaction to Tax Changes Across Heuristics over Rounds

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal Consumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$d_{0,tz}$</td>
<td>13.37*</td>
<td>12.33**</td>
<td>10.19**</td>
<td>11.88***</td>
<td>8.424*</td>
<td>13.95***</td>
<td>8.474***</td>
<td>8.733**</td>
</tr>
<tr>
<td></td>
<td>(1.81)</td>
<td>(2.42)</td>
<td>(2.28)</td>
<td>(3.11)</td>
<td>(1.70)</td>
<td>(2.69)</td>
<td>(2.83)</td>
<td>(2.34)</td>
</tr>
<tr>
<td>$d_{240,tz}$</td>
<td>-31.10***</td>
<td>-7.080</td>
<td>-17.87***</td>
<td>-15.07***</td>
<td>-19.72**</td>
<td>-21.03***</td>
<td>-12.57***</td>
<td>-4.773</td>
</tr>
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<td></td>
<td>(-3.44)</td>
<td>(-1.07)</td>
<td>(-2.88)</td>
<td>(-3.91)</td>
<td>(-2.16)</td>
<td>(-4.78)</td>
<td>(-2.77)</td>
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</tr>
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<td>$\sigma$-Zero-Approximation</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>(1.18)</td>
<td>(0.90)</td>
<td>(2.20)</td>
<td>(3.19)</td>
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<td>(1.60)</td>
<td>(1.25)</td>
<td>(0.64)</td>
</tr>
<tr>
<td></td>
<td>(-1.20)</td>
<td>(-1.87)</td>
<td>(-2.84)</td>
<td>(-3.34)</td>
<td>(-3.14)</td>
<td>(-3.06)</td>
<td>(-2.23)</td>
<td>(-2.37)</td>
</tr>
<tr>
<td>Constant Consumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$d_{0,tz}$</td>
<td>13.32*</td>
<td>-0.0964</td>
<td>18.01</td>
<td>-2.151</td>
<td>5.394</td>
<td>10.31</td>
<td>-4.440</td>
<td>1.631</td>
</tr>
<tr>
<td></td>
<td>(2.02)</td>
<td>(-0.02)</td>
<td>(1.54)</td>
<td>(-0.61)</td>
<td>(0.88)</td>
<td>(0.98)</td>
<td>(-0.81)</td>
<td>(0.26)</td>
</tr>
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<td></td>
<td>(-1.10)</td>
<td>(-1.34)</td>
<td>(-2.47)</td>
<td>(-0.83)</td>
<td>(-0.80)</td>
<td>(0.27)</td>
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<td>(-1.44)</td>
</tr>
<tr>
<td>Fraction of Net Income</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$d_{0,tz}$</td>
<td>140.0***</td>
<td>74.62***</td>
<td>95.70***</td>
<td>35.48*</td>
<td>71.35***</td>
<td>76.45***</td>
<td>85.36***</td>
<td>81.44***</td>
</tr>
<tr>
<td></td>
<td>(5.15)</td>
<td>(3.65)</td>
<td>(4.56)</td>
<td>(1.92)</td>
<td>(4.28)</td>
<td>(5.29)</td>
<td>(7.31)</td>
<td>(5.02)</td>
</tr>
<tr>
<td>$d_{240,tz}$</td>
<td>-69.99***</td>
<td>-81.77***</td>
<td>-59.95***</td>
<td>-77.48***</td>
<td>-83.91***</td>
<td>-54.33***</td>
<td>-58.97***</td>
<td>-63.59***</td>
</tr>
<tr>
<td></td>
<td>(-6.79)</td>
<td>(-6.16)</td>
<td>(-5.15)</td>
<td>(-4.61)</td>
<td>(-7.94)</td>
<td>(-5.35)</td>
<td>(-4.63)</td>
<td>(-7.92)</td>
</tr>
<tr>
<td>Fraction of Cash on Hand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$d_{0,tz}$</td>
<td>41.82***</td>
<td>18.56**</td>
<td>9.625</td>
<td>49.32**</td>
<td>46.79***</td>
<td>21.24</td>
<td>39.87**</td>
<td>35.25**</td>
</tr>
<tr>
<td></td>
<td>(3.95)</td>
<td>(2.26)</td>
<td>(0.50)</td>
<td>(2.23)</td>
<td>(2.97)</td>
<td>(1.56)</td>
<td>(2.24)</td>
<td>(2.40)</td>
</tr>
<tr>
<td>$d_{240,tz}$</td>
<td>-35.51**</td>
<td>-14.04</td>
<td>-34.36***</td>
<td>-40.40***</td>
<td>-55.03***</td>
<td>-42.84***</td>
<td>-47.54***</td>
<td>-35.93***</td>
</tr>
<tr>
<td></td>
<td>(-2.20)</td>
<td>(-1.10)</td>
<td>(-3.99)</td>
<td>(-2.86)</td>
<td>(-5.53)</td>
<td>(-3.66)</td>
<td>(-3.46)</td>
<td>(-3.37)</td>
</tr>
</tbody>
</table>

Notes: The dependent variable is observed consumption ($c_{itz}$). T-statistics based on cluster robust (subject level) standard errors are in parentheses. T-statistics and significance levels refer to tests of the $H_0$ for which the respective variable is equal to zero; significance levels are * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. 
Strikingly, for the constant consumption rule we cannot find any significant effect of taxes in all rounds, except for the tax increase in round 3 and the tax cut dummy in round 1 which are on the 5% and 10% level significantly different from zero, respectively. This is the only rule where tax increases almost never influence consumption significantly. Subjects who use this strategy can therefore be classified as Ricardians throughout.

Turning to the strategies that are predicted to violate Ricardian Equivalence, an entirely different pattern emerges. Again, most of the point estimates on tax cuts and increases are significant. However, the coefficients on tax cuts and increases are much larger than for the other strategies. Moreover, the magnitudes of the coefficients do not appear to decline over the eight rounds.

For example, the tax cut estimate for the strategy to consume a fraction of net income is even larger in round 8 compared to round 2, though this difference is not statistically significant. Similarly, tax increases lead to reactions of comparable magnitude in rounds 1 and 8. This is also true for the strategy to consume a constant fraction of cash on hand. This implies that subjects who employ these rules do not behave according to Ricardian Equivalence, and they also do not react less to tax cuts and increases in the course of the eight rounds.\(^{34}\)

Summing up, reactions to tax cuts and increases are much higher for subjects who appear to consume a constant fraction of cash on hand or net income, compared to subjects who appear to consume optimally or near optimally. People who appear to consume a constant amount show the least reactions to tax cuts and increases.

\(^{34}\)Note that the interpretation is based on a set of subjects assigned to on the round level. Alternatively, one could classify subjects once, according the consumption rule that minimises the RMSE over all eight rounds. Then the extended specifications can be run for each rule of this classification. We instead decided to report the classification on the round basis, because we find that subjects switch consumption rules quite frequently, as is illustrated in Table 7. However, the results are similar and reported in Table C.3 in the Online Appendix.
4 Concluding Remarks and Discussion

In this paper we test whether subjects consume according to Ricardian Equivalence, and whether they learn to comply with the Ricardian Equivalence proposition in a life cycle consumption laboratory experiment.

We find that changes in taxation have significant and strong average effects on consumption in our sample. A tax benefit in early periods increases consumption by about 21% of the tax benefit on average, while a tax increase causes a reduction by 25% of the tax increase.

At the individual level, we find that the behaviour of a significant portion of our subjects can be classified as inconsistent with the Ricardian Equivalence proposition. A conservative estimation suggests that this portion is about 56%. This finding uses evidence on both tax cuts and increases. In survey or register data, often only a tax cut is observed for any one individual. If we test for compliance with Ricardian Equivalence based only on tax cuts, about 34% of our subjects are classified as being not consistent with Ricardian Equivalence.

This finding is similar to those in other studies that employ very different methods. For instance, Campbell and Mankiw (1991) use aggregate data to find the fraction of consumers who respond to changes in current disposable income to be in the range of 35% to 50% for the United States and lower fractions in other countries. Shapiro and Slemrod (1995) find from a telephone survey that 43% of those who responded said they would spend most of the extra take-home pay.

Given the large share of our subjects who violate Ricardian Equivalence, we investigate whether subjects learn Ricardian Equivalence. We find that subjects on average do not appear to learn to consume in accordance with the Ricardian Equivalence proposition. Although subjects in our experiment learn to improve their
consumption decisions, their reaction to tax cuts and tax increases remain significant, even after eight repetitions of the experiment.

In a next step, we show that subjects appear to use different rules of thumbs to approximate optimal consumption, in the spirit of studies like Mankiw (2000) or Galí et al. (2004) that explicitly model two types of consumers (e.g. rule-of-thumb consumers and optimising consumers). We specify a total of five consumption rules and categorise subjects according to which rule best describes their behaviour. We find that the share of subjects whose behaviour is best described by optimising or near optimising behaviour increases over the course of the experiment, from about 40% to about 70%. Moreover, analysing how people switch between the different consumption rules, we find that subjects switch increasingly less to rules that theoretically violate Ricardian Equivalence in later periods compared to early periods. This implies that subjects learn by adjusting their consumption strategy.

Splitting the sample by consumption rules employed, and assessing the impact that taxation has on each of the subsamples individually, we find that the reaction is much smaller for rules that theoretically imply Ricardian Equivalence compared to rules that do not imply Ricardian Equivalence.

Moreover, the magnitudes of the reaction to taxation appear to be decreasing over rounds for subjects who employ rules that imply Ricardian Equivalence, indicating learning, but remain constant for subjects who employ rules that do not imply Ricardian Equivalence. However, due to the small sample size after this split of the sample, these results should be taken with a grain of salt.

While more research is necessary to quantify differential learning, this provides first evidence that subjects learn differently which is reflected in their choice of consumption strategies.

These findings have implications for economic theory: Our results imply that models which incorporate a share of people who do not comply with the Ricardian
Equivalence may be more realistic than models that assume Ricardian behaviour throughout.

Finally, a word of caution might be in order: In our experiment, subjects get to play eight experimental life cycles, while in reality, individuals typically only observe one life-cycle. Hence, the learning observed in our experiment might over-estimate what could be observed outside of the laboratory. Even so, only some of our subjects appear to learn to comply with Ricardian Equivalence in the course of the experiment. The observed failure of the Ricardian Equivalence proposition in this experimental context therefore leaves us somewhat pessimistic about the ability of people to learn Ricardian Equivalence outside of the laboratory.
References


