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Trade and Taxation:

Econometric Evidence from the Taxation of Merchant Ships at the Øresund in the 16th and 17th Centuries

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Abstract

Tariffs may raise revenue today, but at what cost tomorrow? This thesis reveals how overtaxation of foreign trade can harm long-run tax revenues, using a case study with data from the 16th and 17th centuries that is highly relevant today. Focusing on the main shipping route connecting the Baltic and North Seas, the Øresund Strait, the study constructs a reproducible, granular dataset of 7,399,697 standardized ship-level commodity and tax observations from 1497 to 1857. We are the first to present a detailed comparative analysis of the structure and level of taxation in the Øresund, which we use for testing the Laffer Curve in a historical context. By running OLS regressions, we show that overtaxation likely reduced long-run tax revenue, with varying behavioral responses across nations. This work provides a solid framework for future research on historical taxation and combines economic theory with long-run empirical data from a unique historical source.

Keywords: Sound Toll Register Online (STRO), Laffer Curve, Early-Modern Trade and Taxation

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1 Introduction

Imposed tariffs from the president of the United States are expected to result in severe consequences. Trade historian D. Irwin (2025) predicts that the damage will be both economic and geopolitical. A recent paper from Ignatenko et al. (2025) estimates that the imposed tariffs will come at high economic consequences to itself and its partners. The initial estimates suggest that global trade as a share of GDP is expected to decrease by around 11 percent, and worldwide employment is expected to decrease by around 1.1 percent.

This motivates us to look at early modern trade, focusing on taxation implications and their broader consequences. This thesis aims to investigate in detail whether or not continually increasing taxation could lead to diminishing returns. We analyze this through empirical information on the Sound Toll levied by the Danish Monarchy on all merchant ships passing the Baltic-North Sea strait from 1497 to 1857. There is quantitative information over 300 years on early modern trade and shipping of Europe´s main economies (Veluwenkamp & Scheltjens, 2018, p. 1). We present arguments for the Sound Toll as a predatory institution that disproportionately extracted from foreign merchants. Acemoglu et al. (2001) famously proves the lasting economic divergence of countries with extractive or inclusive institutions established during colonial rule and how these institutions continue to shape contemporary economic outcomes. Similarly, Nunn (2009) shows that through path dependence, historical events cast long shadows on present-day institutions, cultures, and economic outcomes.

The importance of the Sound Toll institution was even recognized by Adam Smith, who claimed 'The most important transit duty in the world is that levied by the king of Denmark upon all merchant ships that pass through the Sound" (Smith, 1776, p. 737). We present evidence that this predatory institution, especially under the reign of the Danish monarch Christian IV from 1596 to 1648, represents an exceptional case of how discriminatory taxation at high levels led long-term to a persistent decrease in tax revenue.

For this thesis, we distinguish between the terms: tariff, toll, customs duty, and tax. A tariff is a scale of charges, typically on imports; a toll is a charge to use a bridge or road; a customs duty is a tax on imports or a tariff; and a tax is a compulsory payment to a government or its equivalent (Oxford Reference). We use the word tax as an umbrella term for the others.

Concerns over the consequences of taxation and protectionist trade policies are not just relics of early modern Europe. The current situation in international relations, with a focus on trade, is deeply shaped by uncertainties. These uncertainties are made of taxes set up against a majority of countries in the world, potentially creating a trade war. The Federal Reserve do not know how to act due to these uncertainties and are holding off on changing interest rates to see what the consequences could be (Sherman, 2025). Through the Sound Toll Records (STRO) and with the Danish monarch Christian IV's substantial tariff increases during his reign, we obtain a unique opportunity to derive empirical evidence on the long-term consequences of such aggressive trade policies.

According to Lockhart (2007, p. 53), by the end of the 16th century, before Christian IV's coronation, there was an introduction of an aggressive collection procedure in the Sound Toll that made it much more profitable. In this thesis, we define the aggressive collection procedure as aggressive taxation. As Lockhart (2007, p.133) argues, Christian IV's "wise investments and judicious mulcting of the Sound Dues and other tariffs allowed him to amass a personal fortune unmatched by any other sovereign in Europe". Were these short-run policies successful in the long-run, or did they suppress both tax revenues and trade by overshooting the optimal revenue-maximizing taxation?

Why Historical Trade Policy Matters Today

The overview paper of Lampe and Sharp (2024) on the historical economics of international trade and market integration presents several reasons why economic historians should examine trade. The authors emphasize that the importance of trade rests to a large degree on the knowledge transfer via spillover effects of foreign trade, which implies that trade barriers act as barriers to the world technology pool. Yet, the authors mention an important deviation from this pattern: both the United Kingdom and the United States developed under protectionist regimes. Such knowledge of historical development helps us shape the modern economic theories. Trade has been a large component of the development of economics, and is thus a worthy focus for the field. Furthermore, Lampe and Sharp (2024) notes that economic history allows us to test economic theories by revealing empirical deviations or affirmations from the theory. Acemoglu et al. (2005)'s influential paper on early modern Atlantic trade took a novel empirical approach, examining the quantitative importance of Atlantic ports and investigating differential growth between Eastern and Western Europe from 1500 onward. The authors empirically demonstrate that trade increases led not only to a direct positive economic consequence, but also indirectly to long-run economic growth by inducing fundamental institutional change. They further argue that, in early modern Europe, political institutions were shaped by commercial interests outside the monarchy, often in opposition to royal power.

The Sound Toll's design and persistence can be examined through the lens of institutional theory. According to Olson (1993), the formation of the state often emerges not from collective consensus but from the self-interest of those who can organize coercion. Olson (1993) distinguishes between a stationary bandit and a roving bandit. A roving bandit plunders opportunistically without commitment and creates anarchy, leaving no space for incentives to produce or accumulate anything. A stationary bandit instead settles, monopolizes theft by taxation, and provides public goods to increase productivity and revenue over time, similar to a modern state. Therefore, any stationary bandit rationality would be to maintain a peaceful order with some provision of public good to gain more, especially long-term taxation theft. We propose that Christian IV fits this model of a stationary bandit. As a ruler with autocratic control over toll policy, he extracted revenue through tariffs. While these policies generated immediate fiscal gains, they also carried the risk of future losses, both monetary and social. In line with Olson's warning, excessive taxation can suppress productive activity and ultimately reduce long-run state revenue.

The focus is to investigate aggressive taxation and its implications, where Christian IV serves as an example. We present quantitative evidence from the STRO, showing how discriminatory tax burdens affected tax revenue from different nations to be divided into groups, and analyzing how these changed over time. The STRO serves as an ideal database for this research, due to the extensive ship-level data with over 2.8 million passages and 8.6 million commodities and tolls collected.

To analyze the tax rate-revenue relationship over time, we distinguish three historical stages. This historical stage is centered around the reign of Christian IV. The reign, starting with his coronation in August 1596 and ending with his death in February 1648, serves as our illustrative case study for investigating newly introduced tax policies and their economic consequences. The stage before Christian IV's reign is the baseline to control for differences. The stages are:

- **Before Christian IV** (1557–1596)
- **Reign of Christian IV** (1596–1648)
- **20 Years after Christian IV** (1648–1668)

We present a theoretical relationship between tax revenue and tax rate with behavioral implications. This is usually known as the Laffer Curve, with an inverted U-shape relationship between the two variables. Furthermore, while the economic logic of optimal taxation is central to our analysis and empirically tested, we also acknowledge that Christian IV's excessive tax increases had generated broader consequences. Beyond lost tax revenue, the aggressive policies may have strained diplomatic relations and provoked tensions, as historical records suggest. However, we provide empirical analysis on the dynamic changes in tax revenue, which will be linked with the long-term social costs in the discussion section.

Although the STRO offers exceptionally rich data, certain limitations persist which is recurrent when conducting historical research. The primary challenge for our analysis lies in constructing the Laffer Curve. While tax revenue is known in detail from the STRO, the tax rate, as a ratio of tax revenue to the tax base, remains unknown, as the value of the goods transported is undocumented. We considered approximating the tax base by either the quantity of goods transported or the number of ships passing through the Sound. However, as we explain in section 4, we could not obtain comprehensive data on quantities of goods. Some partial estimates are possible within the STRO, such as the ad-valorem tolls on wine. Another option is to link commodity price data to the STRO, as described in Raster (2024). Yet the scale of research required to obtain precise estimates of goods' values makes this impractical for this thesis. Therefore, we proxy the tax rate by using the number of ships passing the Sound Toll, as detailed in section 4.2. This approach is based on the information, following Gøbel (2010), that the STRO captures almost all shipping activity, as every ship was required to pay at least a nominal light fee. We argue for this proxy under the model specification using the lagged tax revenue as a dependent variable, and the proxy (number of ships) as an independent variable. The lag implementation is crucial for two reasons, first it mitigates reverse causality and second it allows for behavioral adjustments for the shipmaster, this is also discussed in detail in 4.2.

This is the first quantitative analysis looking into early modern taxation in the Baltic sea. The findings in this thesis provide empirical evidence that excessive tax rates can reduce tax revenue. The strength and consistency of this effect vary across tax groups and over time, with low-tax groups showing stronger behavioral responses than the high-tax group.

Section 2 explains the Laffer Curve theory in detail and provides our research question and hypothesis. Section 3 describes the historical and institutional background of the Sound Toll and dives into research on the Sound Toll as well as on early trade, institutions, and economic development. Section 4 begins with a systematic comparative analysis of the structure and level of taxation in the Sound Toll and the data section, and continues with the methodology of our thesis. Section 5 presents the main results of Christian IV's tax rate increases compared to the stages before and after his reign. Finally, Section 6 concludes by discussing the broader implications of our results.

2 Theory and Hypothesis

In this section, we provide the theoretical basis for our empirical analysis. Olson (1993)'s theory of the stationary bandit offers a historical context for Christian IV's fiscal incentives. Our main framework builds on the Laffer Curve theory. We focus on its prediction of an inverted U-shaped relationship between tax rates and tax revenue and its dynamic extension by Buchanan and Lee (1982) to incorporate behavioral adjustment over time. From this, we derive three testable hypotheses: the presence of Laffer Curve effects, potential overtaxation in the high-tax group, and long-run shifts in taxpayer responsiveness.

2.1 Theory

Outlined in the introduction, Olson (1993) theory of the stationary bandit provides a useful lens for understanding autocratic state formation. While we have already established that Christian IV fits this archetype, the deeper logic of Olson's model also provide insights on how and why autocrats may engage in economically counterproductive behavior. Central to Olson (1993) framework is the concept of the encompassing interest defined as the share of total national income the autocrat receives through taxation. This interest determines how much the ruler gains from promoting economic productivity versus extracting immediate resources. The broader the encompassing interest is, the greater the incentive will be to maintain order, protect commerce, and avoid excessive taxation. If the subjects to the regent strongly fear expropriation, the will to invest is damaged, leading to a long-run reduction in tax revenue (Olson, 1993).

However, Olson (1993) emphasizes that the time horizon is key. An autocrat with a short-run focus, due to war, debt, or personal ambition, may choose policies that maximize immediate revenue at the expense of future economic health. This includes raising tax or toll rates beyond the revenue-maximizing level, suppressing trade and production. Such behavior is rational in the short-run but detrimental in the long-run. Olson (1993) further notes that after reaching the revenue-maximizing rate, if increased even more, it will damage the incentives so much that tax revenue will fall due to reduced collections.

This logic closely parallels the structure of the Laffer Curve, in which taxation beyond a certain point leads to a decline in revenue. Economist Arthur Laffer graphically presented the tax rate-revenue relationship in the early 1970s, theorized with an inverted U-shape, establishing what is known as the Laffer Curve (Magness, 2009).

In the politics of trade, D. A. Irwin (1998) notes that it has long been acknowledged that customs duties set beyond the revenue-maximizing tax rate discourage imports, unintentionally leading to a decrease in government revenue. Irwin points out that this is the case because a revenue-maximizing tariff strongly depends on the elasticity of import demand. The demand elasticity is adaptable and depends on price. Assuming constant elasticity is unrealistic because if demand were perfectly inelastic, it would lead consumers to allocate all of their income to those goods (D. A. Irwin, 1998). However, D. A. Irwin (1998) empirically investigates taxation behavior by using an estimated import demand. Due to data constraints, we couldn't obtain import demands. Instead, we formalize the tax rate-revenue relationship using the dynamic framework proposed by Buchanan and Lee (1982), which models both short- and long-run incentives in state fiscal behavior. These frameworks offer explanations for how rulers like Christian IV, via the Sound Toll, could unintentionally undermine their tax base.

Buchanan and Lee (1982) formalizes the revenue-maximizing assumption, that is, an agent that has the right to levy the tax is always seeking to maximize tax revenues. Given this assumption, the logic of the inverted U-shape for the policymaker is to reach the peak of the Laffer Curve, where tariff-induced dead weight losses and producer surplus transfers are minimal (Magness, 2009). Additionally, Buchanan and Lee (1982) in their theoretical paper *Politics, Time, and the Laffer Curve* present a dynamic short- and long-run application of the Laffer Curve. A simplified graph shows the short- and long-run dynamics. We present their graph in Figure 1.

Buchanan and Lee (1982) proposes a definition of long-run as a period where there is enough time to fully adjust for each tax rate. The authors discuss decisions from a governmental perspective, they assume that a full adjustment to rate changes takes two periods, with a political time horizon covering only the first period. This implies that in the short-run, policy makers can increase tax rates more than in the long-run, since the taxpayers have not yet fully adapted to the rate change. Therefore, an excessive increase in the tax rate could be rational, given the short-run perspective.

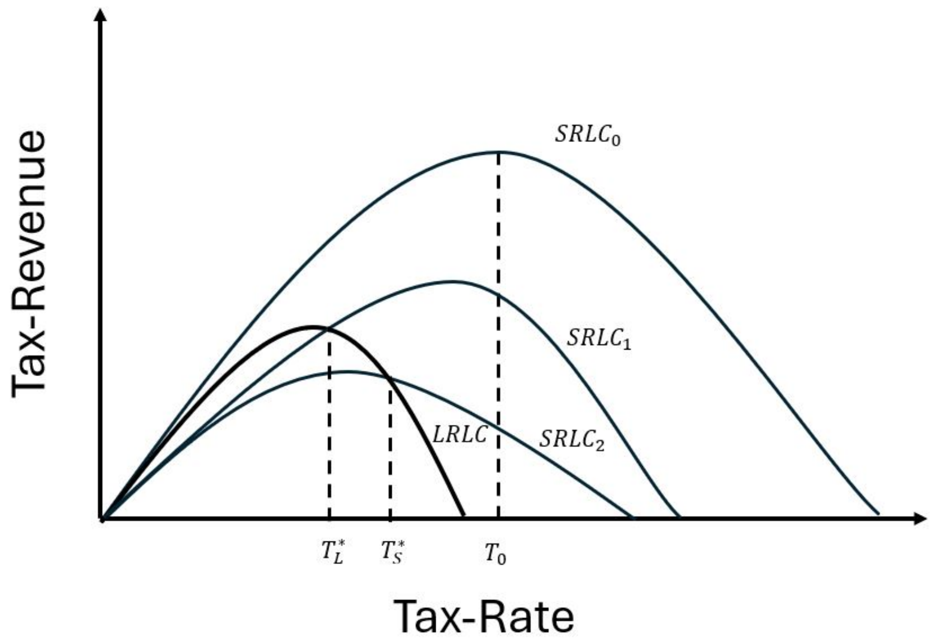

Figure 1: Dynamic Laffer Curves adapted from Buchanan and Lee (1982), Short-Run Tax Rate-Revenue Curves (SRLC) and Long-Run Tax Rate-Revenue Curve (LRLC)

So, policymakers and other interested parties who argue that a decrease in the tax rate will lead to higher tax revenue in the form of economic incentives reveal a more long-term perspective. Policymakers who argue that the government would never operate on the downslope of the Laffer Curve, i.e., beyond the revenue-maximization point, have a short-run perspective (Buchanan & Lee, 1982).

The functional setup presented in a geometrical approach by Buchanan and Lee (1982) is the essence of the logical dynamic showed in Figure 1 with the different Laffer Curves. $SRLC_0$ is a rather extreme short-run case. Here, the decision-makers start from a zero tax rate and are completely unconstrained in their choice, hence having no future view of the coming terms. They then excessively tax to the degree that the tax rate T_0 completely removes the tax base in the coming terms. In $SRLC_1$, the decision makers observe two periods, and are allowed for a period rate increase. Their only interest is the period increase, through which they yield more revenue in the short-run. However, the short-run optimal tax rate T^*_s, presented by the peak of the Laffer Curve $SRLC_2$, is the only tax rate at which the government can maximize short-run revenue, consistent with stable rates through time. T^*_L is the long-run rate optimum inferred by the LRLC.

An early effort to empirically test the Laffer Curve was made by Hsing (1996). The model was then followed by Brill and Hassett (2007), Stinespring (2012), and recently by Wu (2024). As mentioned above, the following studies using the same model, such as Brill and Hassett (2007), Stinespring (2012), and Wu (2024), all find similar evidence of an inverted U-shaped relationship across various contexts, including OECD corporate income taxes, U.S. state tax regimes, and flat-tax economies. We present the Laffer Curve Regression model in:

$$\text{Tax-Revenue}_t = \beta_1 \text{Tax-Rate}_t + \beta_2 \text{Tax-Rate}_t^2 + \varepsilon_t \tag{1}$$

Equation 1 captures the logic of the inverted U-shape. The dependent variable represents tax revenue, and the independent variable refers to the tax rate for the indexed time-series t (e.g., in years, months, or weeks).

The Laffer Curve theory predicts the first coefficient term as positive and the second as negative. Leading to the Laffer Curve hypothesis, the tax revenue initially increases with the tax rate ($\beta_1 > 0$), but decreases beyond the tax revenue-maximizing point ($\beta_2 < 0$). As the necessary condition for testing the Laffer Curve, we allow for non-linearity in the second term. Increases in the tax rate should therefore follow an inverted U-shaped relationship with tax revenue. Hsing (1996) further discusses that optimization theory requires setting the first order condition to zero (Equation 3). The revenue-maximizing tax rate is reached in Equation 4.

$$\text{Tax Revenue}_t = \beta_1 \text{Tax Rate}_t + \beta_2 \text{Tax Rate}_t^2 + \varepsilon_t \tag{2}$$

$$\frac{d(\text{Tax Revenue}_t)}{d(\text{Tax Rate}_t)} = \beta_1 + 2\beta_2 \cdot \text{Tax Rate}_t \overset{!}{=} 0 \tag{3}$$

$$\text{Tax Rate}_t^* = -\frac{\beta_1}{2\beta_2} \tag{4}$$

Hsing (1996) empirical investigation looks at labor supply in the United States from 1959 to 1991, measuring Laffer Curve effects from personal income tax rate on personal income tax revenue. Hsing (1996) finds that the coefficients end up with the expected signs, which implies the inverted U-shaped Laffer Curve. The authors also apply and discuss different functional forms, such as log-log and semi-log. The findings of Hsing (1996) derived the optimal Tax Rate_t^* by taking the first derivative of Tax Revenue_t with respect to Tax Rate_t, and setting it to zero.

2.2 Research Question and Hypotheses

Inspired by the theoretical foundations of the Laffer Curve, we pose the following research question:

> Did Christian IV's Sound Toll policies show evidence of overtaxation across different tax groups during and 20 years after his reign?

To answer our research question, we divide it into three applied hypotheses:

Hypothesis 1 ***No Laffer Curve Effects within Tax Groups***

In our first hypothesis, we test across tax groups and historical stages the significance and the predicted sign for the Laffer Curve for the two coefficients β_1 and β_2 from Equation 1. We first run one-sided tests for β_1 and β_2 separately to understand whether either of the coefficients has contradictory signs. We then test with the joint one-sided hypothesis whether both $\beta_1 > 0$ and $\beta_2 < 0$ hold combined.

We state the one-sided hypothesis for each tax group $g \in \{\text{Low, Middle, High}\}$:

$$H_{0,1}^g : \beta_1^g \leq 0 \qquad H_{0,2}^g : \beta_2^g \geq 0$$

$$H_{A,1}^g : \beta_1^g > 0 \qquad H_{A,2}^g : \beta_2^g < 0$$

In $H_{0,1}^g$, if there is no significant relationship between the tax rate (proxied by number of ships) and tax revenue through the coefficient β_1, against the alternative $H_{A,1}^g$ that there is a significant relationship, cet.par. Next, we test in $H_{0,2}^g$, if there are no significant diminishing returns between the tax rate and tax revenue through the coefficient β_2, against the alternative $H^g_{A,2}$ that there are significant diminishing returns, cet.par. A more negative β_2 implies a stronger concavity of the tax revenue function and suggests that marginal tax rate returns become negative sooner. Secondly, we test the one-sided joint hypothesis on the combined coefficients β^g_1 and β^g_2 for each tax group $g \in \{\text{Low, Middle, High}\}$:

$$H^g_0 : \beta^g_1 \leq 0 \quad \text{and/or} \quad \beta^g_2 \geq 0$$

$$H^g_A : \beta^g_1 > 0 \quad \text{and} \quad \beta^g_2 < 0$$

With H^g_0 we now test that at least one or both of the indicators for a Laffer Curve fails, i.e., the marginal effect is significantly non-positive and/or the curvature is significantly non-negative, against H^g_A where the marginal effect is significantly positive and the curvature of number of ships is significantly negative, cet.par.

Hypothesis 2 ***No Difference between the Revenue-Maximizing Number of Ships from the High-Tax compared to the Middle- and Low-Tax Group***

We compare the location of the Laffer Curve peak across groups. Let $Ships^*_g = -\frac{\beta^g_1}{2\beta^g_2}$ be the estimated revenue-maximizing number of ships for group g, due to our determined proxy, a relative analysis becomes more intuitive than an absolute one. This implies that we can only derive a relative optimum, since there cannot be ”too many” ships from a tax revenue perspective. The Laffer Curve coefficients influence the revenue-maximizing number of Ships in two distinct ways. An increase (decrease) in the positive coefficient β^g_1 increases (decreases) $Ships^*_g$, while an increase (decrease) in the negative coefficient β^g_2 decreases (increases) $Ships^*_g$. We can then separately investigate two-sided tests:

$$H_{0,1} : Ships^*_{\text{High}} = Ships^*_{\text{Middle}} \qquad H_{0,2} : Ships^*_{\text{High}} = Ships^*_{\text{Low}}$$

$$H_{A,1} : Ships^*_{\text{High}} \neq Ships^*_{\text{Middle}} \qquad H_{A,2} : Ships^*_{\text{High}} \neq Ships^*_{\text{Low}}$$

We then define $\Delta_{HM} = Ships^*_{\text{High}} - Ships^*_{\text{Middle}}$ and $\Delta_{HL} = Ships^*_{\text{High}} - Ships^*_{\text{Low}}$, to test the right-tailed joint hypothesis, to infer whether the high-tax group has a higher revenue-maximizing number of ships relative to the two other groups:

$$H_0 : \Delta_{HM} = 0 \quad \text{and/or} \quad \Delta_{HL} = 0$$

$$H_A : \Delta_{HM} > 0 \quad \text{and} \quad \Delta_{HL} > 0$$

Hypothesis 3 ***No Dynamic Behavioral Adjustment to Taxation***

To investigate how taxpayers respond over different time horizons, we compare short-run (lag = 12) and long-run (lag = 52) effects within each tax group g. We use 52 weeks (a full year) as the adjustment period, as it reflects the same season and allows for the plausible assumption that shipmasters would have fully adjusted to new tax policies by then. Let $Ships^*_{g,(w-l)} = -\frac{\beta_{1,g,(w-l)}}{2\beta_{2,g,(w-l)}}$ denote the tax-revenue-maximizing number of ships at tax revenue lag l of week w . Hypothesis 3 tests whether the Laffer Curve shifts by becoming more or less concave over time. The results will then be compared with the dynamic adjustment hypothesis of Buchanan and Lee (1982), where we would expect a shift from T_0 in the $SRLC_0$ to T^*_L in the $LRLC$ when referring to Figure 1 and a more concave Laffer Curve over time.

Sub-Hypothesis 1 *No Difference in the Revenue-Maximizing Number of Ships between Short- and Long-Run*

We formally test whether the estimated peak of the Laffer Curve (denoted $Ships^*$) is the same after 12 weeks and 52 weeks for each tax group g. The null hypothesis asserts no change in the revenue-maximizing traffic, while the alternative implies that shipmasters adjust their behavior over time.

$$H_0 : Ships^*_{g,(w-12)} = Ships^*_{g,(w-52)}$$

$$H_A : Ships^*_{g,(w-12)} \neq Ships^*_{g,(w-52)}$$

This first sub-hypothesis tests whether the revenue-maximizing number of ships differs between lag 12 and 52. A significantly smaller $Ships^*$ at weekly lag 52 suggests that fewer ships can be taxed before tax revenue starts to decline, indicating stronger adjustment from the shipmasters over time.

Sub-Hypothesis 2 *No Differences in Laffer Curve Concavity between the Short- and the Long-Run*

$$H_0 : \beta_{2,g,12} = \beta_{2,g,52}$$

$$H_A : \beta_{2,g,12} \neq \beta_{2,g,52}$$

This second sub-hypothesis tests whether the curvature of the tax revenue function changes between lag 12 and 52. A more concave curve at weekly lag 52 implies that shipmasters are more responsive to changes in taxation in the long-run, reducing the number of ships beyond the optimal point.

Rejection of both sub-hypotheses implies a significant decline in the revenue-maximizing number of ships over time, indicating that the initial tax rate was likely unsustainable. We expect these effects to be strongest in the high-tax group. As a result, the long-run adjustment of the shipmasters that have been taxed too high would decrease the tax base, shifting the Laffer Curve peak leftward.

Our hypothesis framework provides a structured, all-encompassing, testable basis to analyze whether Christian IV's toll policies exceeded revenue-maximizing levels. The three hypotheses allow us to identify Laffer Curve tax effects, overtaxation in the high-tax groups, and long-run behavioral adjustment of taxation.

3 Literature Review

In this section, we give a historical background of the Danish Monarchy and the development of the Sound Toll, as well as an overview of research conducted on the STRO, and lastly, review research conducted on early modern trade.

3.1 Historical Background

Denmark was, in early modern times, a major participant in European international politics. Lockhart (2007) discusses that the three kings who ruled Denmark during its height of greatness, namely, Christian III, Frederik II, and Christian IV, did not necessarily need to change their style of kingship. According to the author, they all applied a model of Germanic tribal kingship from late antiquity. However, the unexpected and sudden death of Frederick II in 1588 left Denmark unprepared, as Christian IV, the eldest son, hence the chosen ruler, was only 11 years old and not yet able to govern. A regency government was necessitated, consisting of a four-man regency (Lockhart, 2007, p.42). Thus, Christian IV became well-prepared to govern after eight years under this Regency supervision, which gave him an extensive political education (Lockhart, 2007, p.128).

The Baltic trade was an interest to the Danish monarchy to control, especially when northern Europe became more dependent on it (Lockhart, 2007, p.104). Similar to Raster (2024), we refer to the Baltic trade as the trade between Baltic Sea ports and the rest of the world from 1497 to 1856. The actors in the Baltic trade were nations and trade guilds with varying market shares over time. Harrison (2024) discusses the main trade guild known as the Hanseatic League, which was an established trade network mostly by northern European towns. During the high and late Middle Ages, the Hanseatic League played a prominent role in the Baltic trade. From the 16th to the late 17th century, the Dutch sequentially dominated the Baltic trade. The Dutch share of all shipping through the Sound rose to be more than 50 percent, at times up to about 85 percent (Gøbel, 2010; Harrison, 2024, pp. 473-476). For the Danish monarchy, the political aim could be expressed as *Dominium maris Baltici*, which means control or ownership over the Baltic Sea. This became a realistic possibility for the Danish monarchy, where they had the potential to restrict the commerce of England, the Netherlands, and the Hanseatic League

(Lockhart, 2007, p.104). Due to the strategic location at the gateway between the North Sea and the Baltic Sea, the Danish monarchy held a significant geopolitical advantage as the primary route for Baltic Trade (Harrison, 2024, p. 482). This geopolitical advantage was a crucial instrument for the Danish monarchy to achieve *Dominium maris Baltici.*

The exceptional advantage was strengthened since the alternative shipping routes were often considered irrelevant for the ship masters (Veluwenkamp & Scheltjens, 2018). Navigation through the *Storebælt* (Great Belt), the first alternative route, was difficult, and there was also a guard ship charging the same toll as in the Sound (Gøbel, 2010). The *Lillebælt* (Little Belt) consists of winding channels and strong currents (Gøbel, 2010), which made it hard for shipmasters to sail through. Therefore, the overland route was the only alternative for low-weight, low-volume, and expensive commodities (Veluwenkamp & Scheltjens, 2018). Furthermore, Gøbel (2010) describes that the Baltic trade was so important that the Dutch came to call it "mother of all trades" during their "golden century". In the later centuries, England's share increased steadily and reached almost a third of all shipping through the Sound (Gøbel, 2010).

The toll was collected at the narrowest part of the strait, located between the current towns of Helsingör on the Danish side and Helsingborg on the Swedish side (Harrison, 2024, p. 482). Taxation of passing ships started in 1497 as a ship toll with a partly fixed price for every ship passing the Sound. Later, a cargo duty was introduced, accompanied by an extensive amount of tolls after some time (Degn, 2018). The toll was of considerable economic importance for the Danish monarchy and played an important role in north and west European politics and shipping. Bookkeeping of the passages trough the Sound began in 1497 in what later became the Sound Toll books, including 1.8 million ships totaling in an amount of at least 86 million *rigsdaler*, calculated to 2010 value by Ole Degn to 1.5 billion *rigsdaler* (Degn, 2018; Gøbel, 2010, pp. 9-10).

The construction of Kronborg Castle started in 1574, and it was strategically located at Helsingør. This castle worked as an instrument to enforce the collection of the toll, threatening ships with cannon fire and destruction. This made it almost impossible to pass the Sound without getting noticed, and even if the shipmasters passed unnoticed, they would likely get spotted by the bookkeepers on the way back to the North Sea (Gøbel, 2010).

Throughout the years, greater wars have taken place that affected the Sound Toll. These were: The Nordic Seven Years War (1563-1570), the Kalmar War (1611-1613), the Thirty Years' War (1618-48), the Karl Gustav War (1657-1660), the Scania War (1675-79), the Great Nordic War (1701, 1709-20), the Prussian Seven Years' War (1756-1763), the Napoleonic Wars (1801-14), and the First Schleswig War (1848-1851). During the Thirty Years War, the Kaiser War (1625-29) and the Torstensson War (1643-45) were fought (Abildgren, 2010; Harrison, 2024, pp. 488-489).

Harrison (2024, pp. 487-488) writes that after the Kaiser War in 1629 and the resulting treaty of Lübeck, the Danish king Christian IV was in an undesirable negotiation position. The war had not been successful for Denmark. Christian IV managed to maintain the lost territory during the war, conditional on keeping away from the internal affairs of the Holy Roman Empire. A decade later came the Torstensson War (1643-45) (Harrison, 2024, pp. 487-488). Between the Kaiser War and the Torstensson War, Christian IV needed to increase his revenues to finance his warfare. The Rigsrådet (council of nobles) opposed increasing taxation of the public. Christian IV's relationship with the council was harmed by the different view on how to finance the war, which further led to a constitutional defeat for the king (Lockhart, 2007, pp. 195-197). Thus, he chose to increase the Sound Toll, which, historically, without interference, has been paid into the king's treasury (Degn, 2018, p.146). The decade from 1630-40 was a significant period of the toll collection. The inflated duties are evident in the many collections of rose noble toll, light fees, cargo duty, defense fees, hundredth penny, thirtieth penny, buoy fees, and other fees (Degn, 2018, pp. 146-148). In 1638, the ship toll was increased by one-third, the cargo toll was multiplied fourfold for several commodities, and the duty of saltpeter was significantly increased. This resulted in increased revenue, which increased from yearly revenues of 223,000 rigsdaler in 1635 to 499,000 rigsdaler in 1641 (Gøbel, 2010). Christian IV closed all belts for foreign shipping (Lockhart, 2007, p. 148). The new Sound Toll schedule of 1638 was thus aggressively enforced. As a result, the Dutch hinted at potential war to protect their commercial interest in the Baltic trade (Lockhart, 2007, p. 202).

”It was inevitable that it would go wrong. Already in 1642 and 1643, the toll had to be moderated, ...” (Degn, 2018, p. 146).

According to Degn (2018, p. 142), since the beginning of the collection of tolls, there existed a hierarchical system with several classes, consisting of privileged and unprivileged nations or regions. Among the most privileged were Denmark, Norway, Sweden, and the Wendish towns, Albeit Wendish towns were not as highly privileged. The second class included the eastern Hanseatic cities, led by Danzig. In the third class were the western Hanseatic cities and the Netherlands, including the province of Holland. The fourth class consisted of the non-privileged England, Scotland, and France. The fifth class was comprised of the town of Emdem (Degn, 2018, p. 142). The different classes were, to a large extent, treated differently at the Sound Toll throughout the centuries (Gøbel, 2010). In the 17th century, the administration of the Sound Toll House went through several changes and became more organized. The relation with the king’s treasury, however, was based on periodical transfers of the collected revenues (Degn, 2018, pp. 76-91). This transfer became more recurrent during the Danish king Frederick IV. From 1702 onward, the Sound Toll House bookkeepers were obliged to make both monthly and annual cash balances (Degn, 2018, p. 91).

The foreign policy of Christian IV in the aftermath was that his foreign policy was overly aggressive and ill-considered. Some historians dismiss him for his selfish striving for power and wealth (Lockhart, 2007, p. 148). Especially the sharp increase in the Sound Toll added up to the most severe diplomatic failing during the second half of his reign, turning previous great companions into unwilling, bitter enemies. By 1643, Denmark was without a significant single ally (Lockhart, 2007, p. 203).

3.2 Research on the Sound Toll

Previous efforts taking advantage of the extensive data set of the Sound Toll records have not been exhaustive. There are still many gaps to be filled. However, a recent working paper published by Raster (2024) uses the STRO to investigate individual pioneering on aggregate trade. The definition of pioneering in this sense is a first mover on a trade link. Pioneering could then have positive spillover effects by generating information on export markets, leading to an aggregation in trade. An approach to measure this taken by Raster (2024) is to use the presence of ice in the Baltic Sea as an instrumental variable, leading to forced rerouting of ships. Raster (2024) shows that ice coverage of the Baltic Sea could be unpredictable in early and late winter. During pre-industrial times, ships were not developed enough to break the ice while en route. Unexpected ice coverage had a significant effect on pioneering activity.

Another effort in using the STRO is done by Marczinek et al. (2022). The authors empirically investigate whether membership in the Hanseatic League over- or under-predicts trade volume, using the gravity model of trade. The hypothesis is that trading capital was accumulated for traders who were members of the Hanseatic League, which allowed them to overcome arbitrary taxation and the risk of expropriation. The authors' finding highlights the importance of networks in shaping trade flows even in the long-run, since the former trade routes after the Hanseatic League's demise continued to outperform other trade routes outside the network cities.

Finally, author Klas Rönnbäck in *Early Modern Shipping and Trade: Novel Approaches Using Sound Toll Registers* by Veluwenkamp and Scheltjens (2018) uses the STRO data to estimate changes in ship turnaround times between 1699 and 1819, finding evidence of increasing shipping speeds. By matching shipmasters across passages to infer broader changes in trade efficiency. The author presents and discusses the mean and median of the time between passages of the Sound Toll. Due to heavy outliers, the median is central to the analysis. This is closely related to the distance of the shipmaster's turnaround. It took roughly 20 days for a round trip between the Sound Toll and Copenhagen, and approximately 67 days for the Sound Toll-St. Petersburg route. Over the full period, median times typically range from 60 to 70 days. These estimates offer the best available proxy for the time lag between a toll increase and the resulting behavioral response from shipmasters. Even though they are at different times from our analysis.

3.3 Research on Early Trade, Institutions, and Economic Development

Wahl (2014) explores the long-lasting effects of trade and commerce during the high and late Middle Ages on modern economic development across European cities. He shows that proximity to historical trade routes and trade centers, identified through mapped trade networks and city-level trade duration indicators, has a persistent impact on contemporary agglomeration patterns. In other words, the advantage of urbanization. Using regional data from the Nomenclature of territorial units for statistics (NUTS) classification and a broad set of controls, the paper highlights how historical trade institutions and activity can shape long-run economic trajectories, emphasizing the enduring role of commerce in regional development.

Another study by Ljungqvist and Seim (2024) focuses on price grain price variability during early modern times in Europe from 1500 to 1800. The motivation to focus on grain is that it was considered the most important product in Europe during this time, as it constituted 70 to 80 percent of the calorie intake for the majority of the population. This implies that grain price could be considered as an indicator of the overall food supply situation. The authors show that price variation of grain significantly depends on agricultural technology, climate and weather variations, demographic changes, inflation, and warfare. Furthermore, the price stabilization is affected by war as a direct effect and then as an indirect effect via a population decrease. Leading to a lasting decline in the demand for grain in the region, e.g., in the case of the Thirty Years' War (1618-1648).

4 Data and Methodology

This section presents the historical dataset, empirical model, and econometric strategy used to evaluate the presence and structure of Laffer Curve effects in the Sound Toll. For this analysis, the STRO, a uniquely rich fiscal source covering over three centuries of European maritime trade, is used. We carefully prepare the data by categorizing toll types, standardizing commodities, and grouping nations into low-, middle-, and high-tax categories. Descriptive statistics, time series trends, and tax-rate distributions between nations are provided to enrich our analysis.

”The toll was unique, of importance for a great part of Europe, and a similar row of accounts for a period of more than three hundred years is found nowhere else.” (Degn, 2018, p. 139). ”(...), it provides a good view of the goods exchange between the Baltic Sea and the rest of the world.” and ”will be a unique tool for the scholarly investigation of shipping and trade (...) between 1497 and 1857 (Gøbel, 2010).

4.1 Data: The Sound Toll Registers Online

The Sound Toll Register (STR) is well known as one of the most detailed and rich information on European shipping and trade sources of early modern history (Veluwenkamp & Scheltjens, 2018). The STRO is the electronic database of the complete STR, covering the years 1497 to 1857, created jointly by the University of Groningen and the Frisian Historical and Literary Centre at Leeuwarden (Tresoar). “The STRO consists of ten tables that were finalized in May 2020. The STR data contains 1.8 million passages through the Sound.” (soundtoll.nl). The data set includes information for date, name of shipmaster, the shipmaster’s residence, port of departure, port of destination from 1666, the composition of the cargo, and the type and amount of ship toll paid in the respective currency. We give a detailed explanation of the creation and extensive preparation of the STRO database in Appendix A. It is important to remember that the STRO is a fiscal source and was not made at the time for statistical analysis (Veluwenkamp & Scheltjens, 2018).

4.1.1 Systematic Comparative Analysis of the Structure and Level of Taxation in the Øresund

Figure 2 provides the first overview of the yearly amount of the Sound Toll levied on the merchant ships. From the second half of the 16th century up until the death of Christian IV in 1648, we observe both a high number of ships and a high tax revenue. Following the reign of Christian IV, succeeding Danish monarchs did not raise tolls to offset inflation.

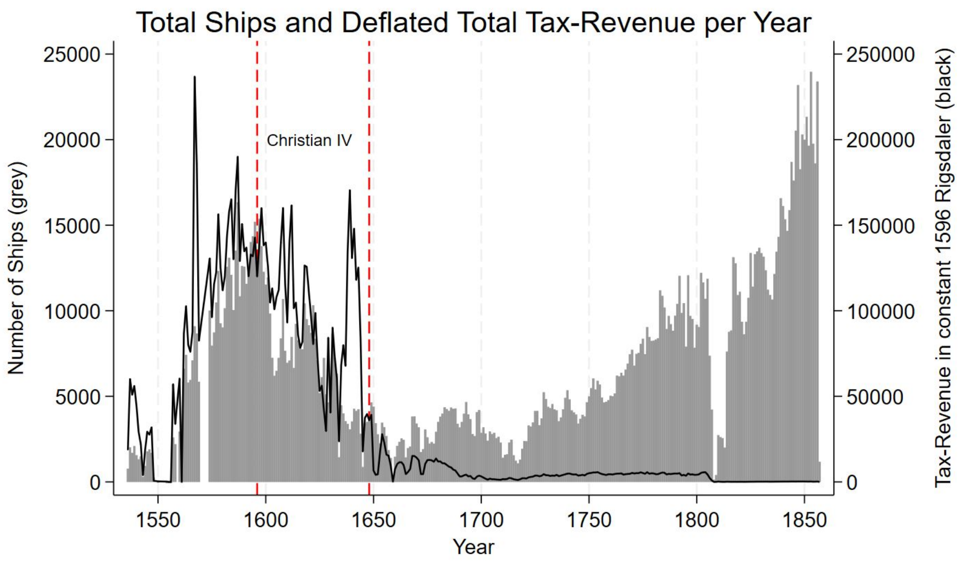

Figure 2: Total Ships and Deflated Total Tax-Revenue Over Time

We first present descriptive statistics of the main taxes by deflated value in constant 1596 Rigsdaler, separated into our three stages (before, during, and after Christian IV) in Table 6 (highest value on the top, then decreasing). We also present the summary statistics in nominal terms in Table 7. We see that *Lastpenge* is the most relevant toll levied before and during the reign of Christian IV. *Lastpenge*, translated from Danish into English, means Cargo Duty. In the period after Christian IV, Cargo Duty became the most relevant toll levied. We describe the distinction between *Lastpenge* and Cargo Duty in the "Toll Types in Detail" subsection, and continue by firstly describing the toll types in detail.

Cargo- and Tax-Duties

In our data structure, we make a fundamental distinction between Cargo Duties and Tax Duties. Cargo-Duties derive from the original *Cargo/ladingen* table. Tax-Duties derive from the *Taxes/belastingen* table. We start by separating tolls into Tax Duties and Cargo Duties. Figure 12 shows their development over time. Given that the Cargo Duty appears only from the 1680s onward, we examine whether *Lastpenge* served as its equivalent in earlier periods. Figure 13 supports this assumption, showing a clear replacement from *Lastpenge* towards Cargo Duty in January 1681. The descriptions of tolls in Degn (2018) do not mention any changes in 1681, which may be attributed to the fact that his work approaches the Sound Toll from a historical rather than a data-analytical perspective. We attempted to determine whether this change was made by the Danish bookkeepers or the Sound Toll team during the construction of the database. We found no evidence pointing in either direction. What we did find, however, are two illustrative entries from the STRO showing the changed entries: Passage 713129 from 1680 without (Figure 14), and Passage 719739 from the same year with a Cargo Duty (Figure 15). Figure 13 also illustrates the seasonal variation in the STRO data, as described by Raster (2024). Each season follows a bell-shaped curve, with trade volumes peaking in mid-summer and reaching their lowest levels during the winter months.

Tolls Types in Detail

We present summary statistics on the ten highest valued taxes for each of the three stages in Table 6 in the Appendix. To illustrate changes in toll revenue composition over time, we present a line graph of toll revenues separated by toll types during the reign of Christian IV from 1596 to 1648 and the summarized other tolls in Figure 3. The translation and explanation of each toll in detail can be found in Table 8. During the reign of Christian IV, *Lastpenge* (Cargo Duty) was the main toll, generating approx. 2.85 million constant 1596 rigsdaler. Revenues from the other tolls amounted to approx. 2.38 million constant 1596 rigsdaler. We scatterplot *Forhøjelsen*, since it was levied only in specific years. We could interpret the *Forhøjelsen* toll as an attempt to gain higher tax revenues, even though the number of ships was declining (higher per ship revenues). The introduction of *Forhøjelsen* aligns with the burning of Kronborg Castle in 1629.

After successfully deflating the toll revenues to constant 1596 rigsdaler, we tried to make the distinction between fixed and variable tolls in the STRO dataset. Unfortunately, we still see a high variation in supposedly fixed tolls, such as the *skibstold* (ship toll). For variable tolls we see, as expected, very high variations, e.g., in the Cargo Duty. Our summary statistics with decade-long observation periods of each stage make it unfeasible to establish a separation into fixed and variable tolls.

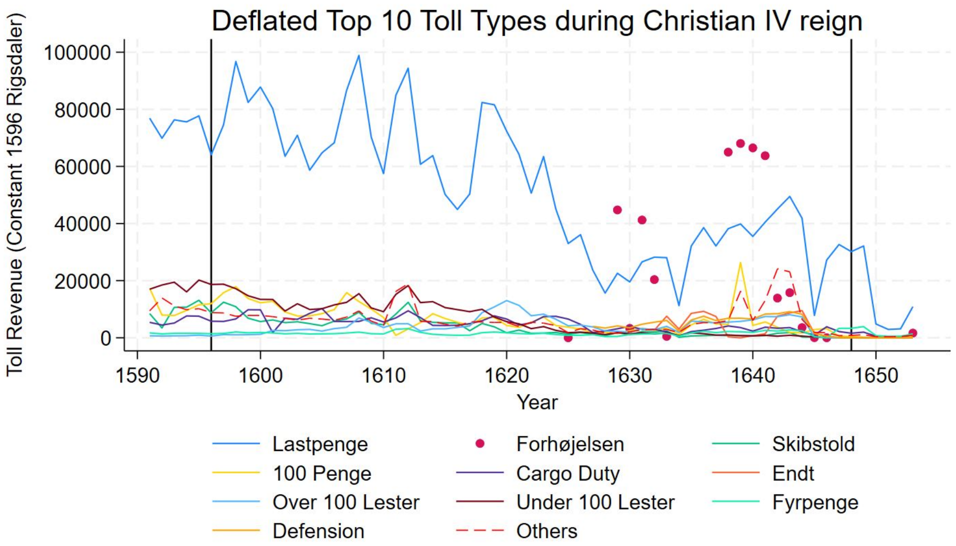

Figure 3: Yearly Toll Revenues during the Reign of Christian IV from 1596 to 1648, Separated by the Ten Highest Valued Taxes and Summarized Others. A description of each Toll can be found in Table 8.

Commodity Classification

To use the commodities for our analysis, we had to do extensive standardizations, which we explain in detail in Appendix A. After our standardization and classification of the commodities taxed in the Sound, we have translated and categorized 4,511,088 out of 5,568,590 (i.e., 81.01 percent) total commodities. Table 1 shows the distribution of the ten commodity categories, and a summary table of the commodity categories in the three time periods can be found in Table 9. We acknowledge that the category "Other" likely includes commodities belonging to other groups. Due to time constraints, it was not feasible to identify each of the 1,550 unique standardized commodities and determine in which appropriate category they might fit.

We draw a graph on the average cargo duty paid per category over time, as shown in Figure 4. It is important to mention that the average Cargo Duty is not an average of quantity, but only the average Rigsdaler paid per occurrence of the commodity category. The Cargo Duty was only charged from 1680 onward (with a minor exception of alcohol

Table 1: Distribution of Commodities by Category

Category	**Freq.**	**Percent**	**Cumulative**
Alcohol & Beverages	146,620	3.25	3.25
Ballast	372,322	8.25	11.50
Grain & Food	718,915	15.94	27.44
Livestock & Animal Products	139,638	3.10	30.54
Metals & Minerals	560,673	12.43	42.96
Other	1,387,153	30.75	73.71
Spices & Luxury Goods	149,892	3.32	77.04
Textiles & Clothing	344,995	7.65	84.68
Weapons	16,279	0.36	85.05
Wood & Timber Products	674,601	14.95	100.00
Total	**4,511,088**	**100.00**	

and beverage tolls in the earlier 17th century). From a plain look at Figure 4, we see that the different commodity categories' compositions are fairly homogeneous in their average amount of Cargo Duty. Wood and timber products (considered bulk goods) were taxed at the lowest rate of all commodities. Livestock and Animals, as well as Grain and Food, were taxed the highest until the composition changed significantly after 1750. Then, alcohol and beverages and spices, and luxury goods, and from 1800 also textiles and clothing, take off. A likely explanation for the later development is that the quantities of alcohol, beverages, spices, and luxury goods increased significantly during the period of colonial expansion (Rönnbäck, 2010), leading to a corresponding rise in tolled duties.

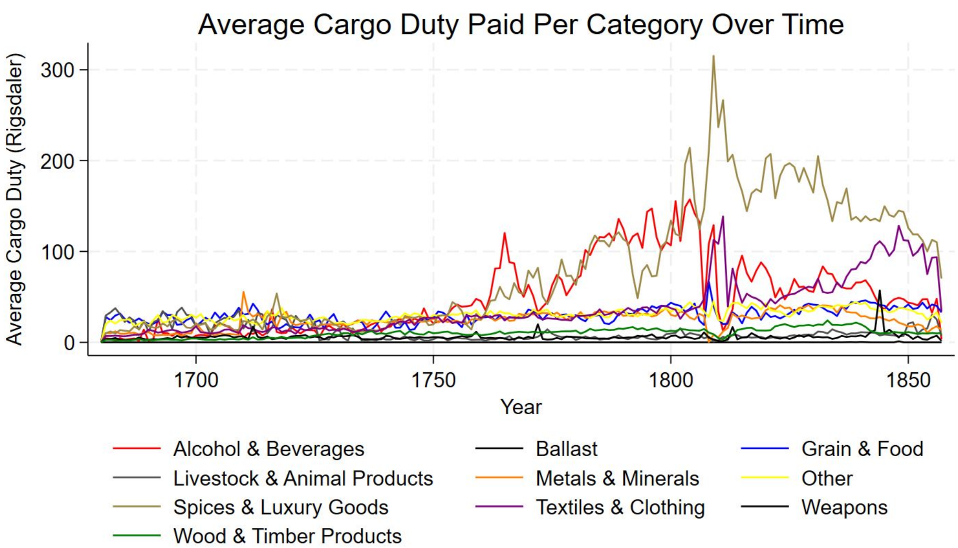

Figure 4: Average Cargo Duty per Category over Time, starting 1680

Nations and Tax-Groups

We are now able to identify the nationality of each shipmaster. We identify nations in the same manner as seen in Raster (2024). These national categories are: Denmark & Norway, the Hanseatic League, the Netherlands, other German cities, the United Kingdom, and Sweden. We group all other cities into ”Others”. The German nation represents an exception in the early modern European landscape. Münkler (2019) explains in detail why the German nation developed comparatively late to other European nations. During the time of our case study on Christian IV, Germany was not yet unified. The cities of the Hanseatic League still had significant market shares of approximately 20 percent in the Baltic trade (see Figure 5). Given its historical and economic relevance, we treat the Hanseatic League as a distinct “nation” for the purposes of our analysis. A comprehensive study on the Hanseatic can be found in Dollinger (1970). Summary statistics by nation are provided in Table 11. For our comparative analysis, we classify nations into three tax groups based on the mean and standard deviation of the toll paid per ship, as well as from Degn (2018, pp 142-143). Denmark & Norway and Sweden are grouped into the low-tax category, the Hanseatic League and other German cities into the middle-tax group, and the Netherlands, the United Kingdom, and other nations into the high-tax group, where the Netherlands by far has the highest share (see Figure 5). We present box plots of the average toll paid per ship during each stage of the tax groups in Figure 6. The plots clearly illustrate systematic differences in the taxation burden across tax groups in each of our three periods.

4.1.2 Data Structure

From our cleaned masterfile with 7,399,697 observations and 31 variables in the long format, we construct a dataset which includes dummies of each of the toll type, commodity categories, week of the passage, and if the passage happened during one of the specific wars identified by Abildgren (2010). The dataset is divided into the four historical stages: Before Christian IV (1497 to 08/1596), with 920,338 observations, the reign of Christian IV (08/1596 to 02/1648) with 1,508,012 observations, the stage 20 years after Christian IV (03/1648 to 12/1668) with 181,009 observations, and the remaining time (01/1669 to 04/1857) with 4,790,338 observations. For our analysis, we collapse the dataset to a

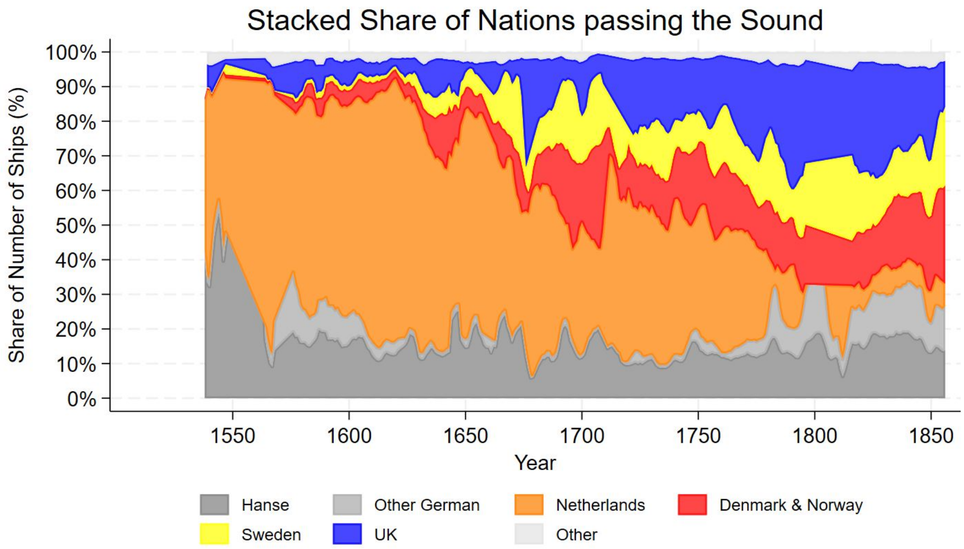

Figure 5: 4-Years Centered Moving Average Share of Ships passing the Sound from Major Nations. Adapted from Raster (2024).

week level by summing ship counts and tax revenues, and panel-set the data for each of our three tax groups. We obtain an unbalanced panel in the wide format with weekly data ranging from week 6 of 1537 up to week 39 of 1857. In total, we observe 39,520 tax group-week observations: 13,019 weeks for the low-tax group, 13,264 for the middle-tax group, and 13,237 for the high-tax group.

To run regressions properly, we balance the panel by adding observations for weeks in which no ships passed through the Sound. From the section 3, we are confident that these zero-ship weeks reflect true inactivity. Especially when considering seasonality and the freezing of the Baltic Sea during winter (Raster, 2024). During wartime, these assumptions may not always hold. We add 7,293 such zero-ship weeks, so that the total number of weekly observations increases to 46,813. Through this, we obtain a balanced panel dataset with approximately. 301 years of weekly observations (46,813 ÷ 3 tax groups ÷ 52 weeks per year).

4.1.3 Limitations and Possibilities of the STRO

A detailed explanation of our data cleaning can be found in our Data Appendix A. Due to time constraints, we were unable to standardize the unit of measure (variable called *maat* in the STRO), which also prevented us from utilizing the amount (*aantal*) of the

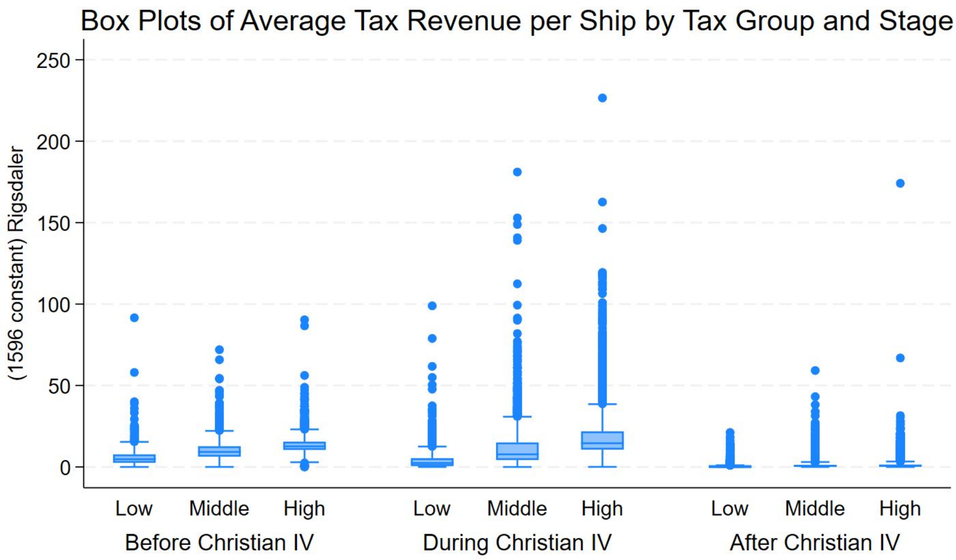

Figure 6: Average Tax Revenue per Ship by Tax Group (Low, Middle, High) and Stage (Before, During, After Christian IV). For visibility, Week 11 in 1644 in the Middle Taxed Group, with Average Tax Revenues of 418 Rigsdaler, has been excluded.

taxed commodities. With additional time, it would have been possible to approximate the quantity of the commodities in modern measurement units, such as liters and kilograms. The soundtoll.nl provides a Danish description of historical measurement units, along with a list of relevant external resources (link). We therefore cannot estimate the percentage tax rate of commodities.

It is relevant to acknowledge the existence of fraud in the STRO. Shipmasters sometimes evaded taxation by false declarations of the commodities their ships carried (Veluwenkamp & Scheltjens, 2018) and Concise source criticism of the original STR. Even if the customs officers were entitled to search the ship, they generally did not (Gøbel, 2010). Fraud was most common with high-value, low-volume commodities, whereas bulky commodities were harder to hide. From 1580 to 1618, it is plausible that fraud could range between 25 to 50 percent of all commodities. The fraud rate decreased in 1618, when the customs officer carried out checks more systematically (Veluwenkamp & Scheltjens, 2018). Another consideration from Gøbel (2010) is that certain nations were exempted from the toll. They were still registered, but relevant cargoes and especially volumes are unknown.

4.2 Methodology

After presenting and discussing the Laffer Curve in the section 2, we now construct our model specification to test our hypotheses. Stated in Hsing (1996), the general form of the Laffer Curve is seen in Equation 2.

4.2.1 Empirical Model

For the general Laffer Curve estimation, we need data on the tax revenue and the tax rate, as seen in Equation 2. Our model specification has to be modified compared to Hsing (1996). This is due to the dataset providing us with the tax revenue, but not the value and quantity of the shipped commodities. Since the value of the commodities is unobserved, we are unable to directly derive any tax rate. Thus, we proxy the tax rate by the number of ships passing the Sound. This is founded on the information from Gøbel (2010) that all shipping through the sound is documented. The logic of our proxy is, that the tax-revenue does not come from the passing of ships in itself, it comes from the tax paid by those ships that passes the Sound, therefore it allows us to use the number of ships as a proxy for the taxed value which yields the tax revenue, given that all ships paid the toll. An important distinction is the division of the taxation arrangement in the Sound Toll. For this, we have constructed different tax groups that were exposed structurally differently to the tax rate, as seen in Figure 6. The different tax groups enable us to capture differences in toll exposure, which forms the basis for tax-level comparisons in the analysis. Our model specification is thus presented as follows:

$$\text{Tax-Revenue}_{g,(w-l)} = \beta_0 + \beta_1 \cdot \text{Ships}_{g,w} + \beta_2 \cdot \text{Ships}^2_{g,w} + C_{g,w} + \varepsilon_{g,w} \tag{5}$$

We implement an Ordinary Least Squares (OLS) regression on each tax group g during week w with lag l on the dependent variable. Since we are given the actual entire population and not a sample dataset, we choose to estimate a linear model despite the high skewness and variance of both tax revenue and the number of ships.

We decided to implement lags on the dependent variable for two main reasons. The first is for the shipmaster to adapt to the increased taxation in the Sound Toll. Especially given the fact that our time frame takes place in early modern times, and the information exchange was presumably far from perfect compared to today. Leading to a delayed behavioral response of taxation, aligning with known information and reaction lags in historical maritime trade (Raster, 2024). The second reason to implement lag is due to tax revenue is a direct function of the number of ships, leading to a severe reverse causality concern. To get around this, we lag the dependent variable, assuring that the increase in taxation is affecting the tax revenue and not vice versa. From this view, it is plausible to assume that the number of ships is rather exogenous for the Sound Toll administration. The information about the time between passages of the Sound Toll is derived from Ronnback (2012), discussed in the literature review. The overall discussed median time traveled is about 60-70 days, thus referring to around 10 weeks in our model specification.

We collected four controls for our regressions:

The commodity categories that should equalize systematic differences in the commodity compositions. If, e.g., Dutch shipmasters traded significantly more colonial goods, this control should capture it. A detailed explanation of the different commodity groups can be found in our Systematic Comparative Analysis on the Structure and Level of Taxation in the Sound earlier in this section.

Times of war, since we think that wartime changes trading behavior, and that we should capture these changes. We code a dummy variable if the week was within one of the wars described in Table 5, which we take from Abildgren (2010).

We capture seasonality effects via dummies of the week of the year of the observed week. Ships faced the presence of ice during the winter months. Given the absence of icebreaker ships at the time, this affected the passage of ships through the Sound. Primarily in December, January, and February, implied near-zero traffic during the winter months. Week 1 in January, therefore, has a negative effect on the tax revenue, whereas a week in August has a positive effect. See seasonal variation in Figure 13.

The final control we include is the toll *Over 100 Lester*, which was levied based on a ship's cargo capacity. We consider this a valid proxy for ship size, as ships with greater carrying capacity were likely subject to higher tolls. The data shows us that approximately 95 percent of *Over 100 Lester* were paid by Dutch ships. This fact is also mentioned in Degn (2018, p. 268). The control effect of the ship size is therefore mainly in the high tax group.

4.2.2 Econometric Strategy

We explain how the theoretical Laffer Curve is converted into a practical, testable econometric strategy using the hypotheses presented in section 2.2 and building upon the model specification introduced in section 4.2.

Our identification strategy depends on variation in the weekly number of ships passing the Sound across tax groups and stages. The tax rate variation is mainly dependent on the type and quantity of commodities transported, the shipmaster's nationality, and the size of the ship. We aim that our discussed controls capture most of this variation, so that only tax rate de-/increases are captured, and we can assume that tax rates are relatively stable within each group during a given stage.

By estimating how the lagged tax revenue depends on the non-linear number of ships, we estimate behavioral responses to taxation. The number of ships proxies as well as the effective tax base, which may shrink or expand in response to the tax burden. Through the changing number of ships, we then infer whether the tax rate exceeded its tax-revenue-maximizing level in different groups and periods.

Lastly, we provide directions for sensitivity analyses and further model specifications for robustness checks.

5 Results and Analysis

This section presents the empirical results of the three hypotheses derived from Laffer Curve theory. First, we find consistent evidence of non-linear tax-revenue relationships across groups and time, supporting the evidence of Laffer Curve effects. Second, the high-tax group appears to have exceeded its revenue-maximizing point relative to the middle- and low-tax groups, suggesting overtaxation. Third, we test whether shipmasters' behavior adjusts over time. While the low-tax group shows signs of long-run responsiveness, the middle- and high-tax groups do not. These findings combined suggest that Christian IV's toll policies may have introduced inefficiencies, particularly for heavily taxed nations, and that behavioral responses varied substantially across tax burdens and historical periods.

Results for Hypothesis 1: No Laffer Curve Indication within Tax Groups

The model specification is conceptualized in the Hypothesis 1, and its results are shown in Table 2 for the different tax groups and historical stages. We present various lags of interest to allow for some adjustment time and to mitigate reverse causality. Further, the OLS estimation uses robust standard errors to account for heteroskedasticity.

In our specification, we implement and mainly present the lagged tax revenue. However, we decided to include zero lags in the result table to show how the model predicts when there is not enough time for adaptation, that is, within the specific week. We can see no indication of an inverted U-shape when zero lag is implemented, the second term is dominantly non-negative, and when observed negative, it is insignificant. However, as mentioned in the methodology section, tax revenue is a direct function of the number of Ships, so when no lag is implemented, we would expect severe reverse causality.

This becomes apparent when analyzing the R-squared in the non-lag versus lag estimations. The R-squared drastically decreases in the lagged models compared to the zero-lag. Since it is of no further interest to analyze the R-square for this model specification, we do not present it. On lagged tax revenue throughout the table, we observe the expected signs according to theory, i.e., the first term of the number of Ships is positive and the second squared term is negative. When the second squared term is negative and significant, the Laffer Curve has the inverted U-shape. The majority of the coefficients are statistically significant. Hence, we reject the first null-hypothesis presented. This is due to the significance level being less than or equal to the conventional predetermined range of p-value. The interpretation of the model becomes the effect of increase in taxation on future revenue. Due to our proxy it can either be that they sailed less or that the Sound Toll collected less. To nuance this intuition, we remind ourselves by Figure 2.

In comparison to the different tax groups, we can spot differences in reaction through the results. In general, we can detect a stronger reaction for the low-tax group than the high-tax group. This is because the curvature becomes more concave in the lower tax group, since the second coefficient is of higher magnitude than in the high tax group. We provide a graph with β_2 coefficients in Figure 7 for the reign of Christian IV, as well as before and after his reign in the Appendix in Figure 17 and Figure 18. This will be further analyzed in the second hypothesis, where we then analyze and compare the optimum point of the lagged tax revenue function for the different tax groups and stages.

Instead of using the separately tested coefficients for Hypothesis 1, we implement a one-sided bootstrap test for the joint hypothesis. The results are visualized in Figure 9, which presents bootstrapped p-values from 100 draws per specification. Compared to our results, the coefficient-by-coefficient testing presents a similar, but clearer picture. Before Christian IV's reign, we observe consistently significant Laffer Curve effects for all tax groups and lags (besides no lag, as expected). During Christian IV's reign, the effects were less significant, especially for the highly taxed group. In the 20 years after Christian IV, the Middle-Tax group had the most significant effects.

Table 2: Effects of Weekly Number of Ships on Lagged Tax-Revenue by Tax Group Across Periods

	Before Cristian IV 1557 - 1596						**During Cristian IV 1596 - 1648**						**After Cristian IV 1648 - 1668**					
	Low-Tax		Middle-Tax		High-Tax		Low-Tax		Middle-Tax		High-Tax		Low-Tax		Middle-Tax		High-Tax	
Lag	Ships	Ships^2	Ships	Ships^2	Ships	Ships^2	Ships	Ships^2	Ships	Ships^2	Ships	Ships^2	Ships	Ships^2	Ships	Ships^2	Ships	Ships^2
0	4.684***	0.0164**	7.441***	0.00336	16.29***	0.00125	2.874***	-0.0215	3.681***	0.0120***	5.728***	0.00073	1.033***	-0.0216**	3.551***	0.0271	4.324***	0.0127***
	(0.520)	(0.00828)	(1.147)	(0.00283)	(1.383)	(0.00154)	(0.523)	(0.0132)	(0.726)	(0.00298)	(0.957)	(0.00204)	(0.222)	(0.00909)	(0.830)	(0.0194)	(0.809)	(0.00354)
2	4.629***	-0.0799***	8.882***	-0.0303***	15.20***	-0.0157***	0.754*	-0.0278***	3.606***	-0.0079	4.118***	-0.0076***	0.600**	-0.0234**	4.169***	-0.0252	5.441***	-0.0271***
	(0.733)	(0.0122)	(1.470)	(0.00405)	(2.611)	(0.00236)	(0.403)	(0.0077)	(1.012)	(0.0058)	(1.183)	(0.0020)	(0.248)	(0.00984)	(1.043)	(0.0212)	(1.400)	(0.00580)
4	4.680***	-0.0715***	9.835***	-0.0290***	10.68***	-0.0109***	1.189***	-0.0308***	3.435***	-0.0114**	1.739	-0.0028	0.618**	-0.0137	4.335***	-0.0320*	3.530**	-0.00924
	(0.736)	(0.00947)	(1.336)	(0.00372)	(2.439)	(0.00229)	(0.370)	(0.0075)	(0.865)	(0.0057)	(1.209)	(0.0023)	(0.251)	(0.0101)	(0.990)	(0.0181)	(1.461)	(0.00693)
6	4.898***	-0.0690***	7.692***	-0.0302***	10.42***	-0.0112***	0.356	-0.0202**	3.536***	-0.0107**	1.261	-0.0051**	0.777***	-0.0220**	2.654**	0.00231	2.863**	-0.0152***
	(0.687)	(0.00891)	(1.207)	(0.00314)	(2.195)	(0.00195)	(0.447)	(0.0087)	(0.861)	(0.0045)	(1.280)	(0.0024)	(0.217)	(0.00896)	(1.052)	(0.0245)	(1.295)	(0.00581)
8	3.669***	-0.0705***	7.481***	-0.0274***	10.11***	-0.0106***	1.502***	-0.0381***	2.631***	-0.0085*	1.680	-0.0062***	0.417*	-0.0157**	3.243***	-0.0262	3.978***	-0.0141***
	(0.713)	(0.0103)	(1.293)	(0.00271)	(2.406)	(0.00169)	(0.375)	(0.0068)	(0.957)	(0.0051)	(1.095)	(0.0017)	(0.219)	(0.00725)	(0.886)	(0.0195)	(1.437)	(0.00523)
10	3.581***	-0.0541***	6.661***	-0.0192***	9.595***	-0.0110***	1.103***	-0.0325***	2.074**	-0.0116**	0.142	-0.0018	0.455**	-0.0166*	3.556***	-0.0348**	2.383**	-0.0117**
	(0.701)	(0.0104)	(1.280)	(0.00591)	(2.113)	(0.00163)	(0.371)	(0.0070)	(0.885)	(0.0046)	(1.076)	(0.0020)	(0.214)	(0.00852)	(0.875)	(0.0167)	(1.200)	(0.00477)
12	3.406***	-0.0641***	6.948***	-0.0167***	7.720***	-0.00877***	0.830**	-0.0267***	2.878***	-0.0148***	1.269	-0.0047***	0.484**	-0.0208***	4.795***	-0.0545***	3.492**	-0.0123**
	(0.709)	(0.0108)	(1.127)	(0.00375)	(2.213)	(0.00135)	(0.375)	(0.0072)	(0.716)	(0.0032)	(0.986)	(0.0016)	(0.190)	(0.00670)	(0.813)	(0.0155)	(1.483)	(0.00573)
52	2.522***	-0.0432***	7.469***	-0.0178***	7.707***	-0.00870***	1.416***	-0.0355***	4.520***	-0.0121**	4.285***	-0.0032	0.716**	-0.0297***	5.471***	-0.122***	1.791	-0.0128
	(0.743)	(0.0129)	(1.371)	(0.00327)	(2.401)	(0.00151)	(0.411)	(0.0082)	(0.958)	(0.0054)	(1.268)	(0.0024)	(0.288)	(0.0106)	(1.069)	(0.0180)	(1.799)	(0.00893)

Notes: Robust standard errors in parentheses. All regressions include controls: `toll_over100`, `category_*`, `war_*`, and `week_*`.

The Tax Groups are: Low-Tax = Denmark and Sweden; Middle-Tax = Hanse and other German cities; High-Tax = Netherlands, United Kingdom and Others.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

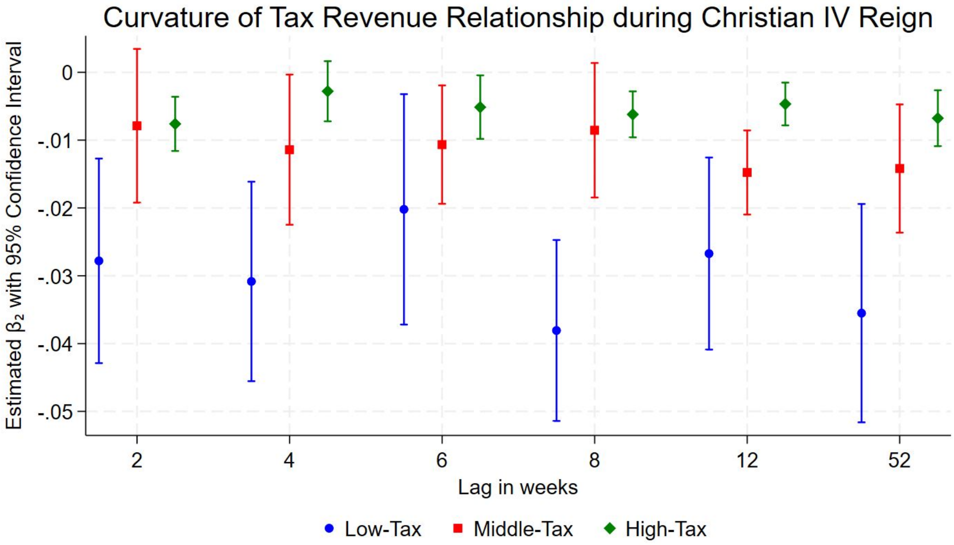

Figure 7: β_2 Coefficient of $Ships^2$ per Lag during the Reign of Christian IV (1596-1648) with robust 95% Confidence Intervals

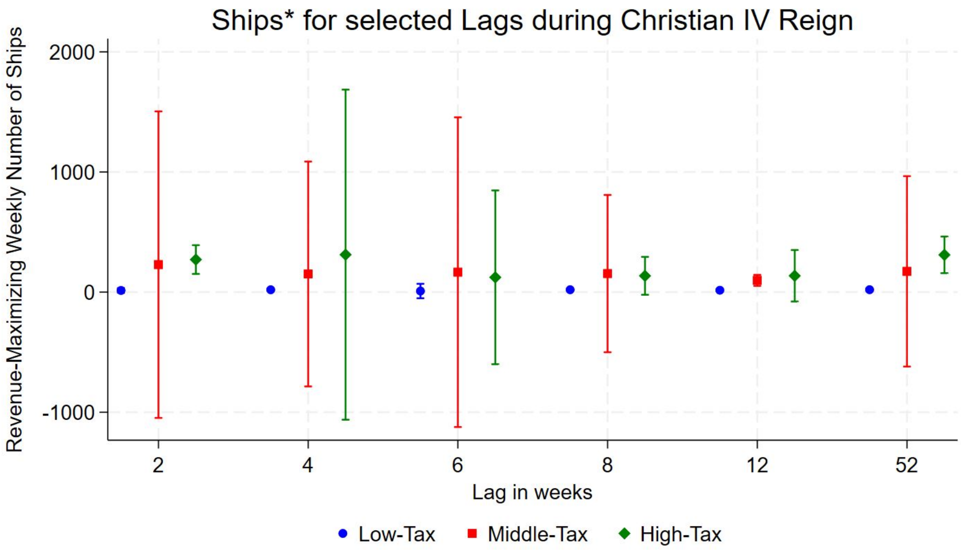

Figure 8: Optimal Weekly Number of Ships per Lag during the Reign of Christian IV (1596-1648) with bootstrapped robust 95% Confidence Intervals

Results for Hypothesis 2: No Difference between the Revenue-Maximizing Number of Ships from the High-Tax compared to the Middle- and Low-Tax Group

To test for comparative differences between groups, we calculate the tax revenue maximizing number of ships from Table 2 for each tax group. Since we proxy the taxation with number of Ships, we are interested in a comparative analysis between the tax revenue maximizing number of Ships of each tax group as we believe it becomes more intuitive.

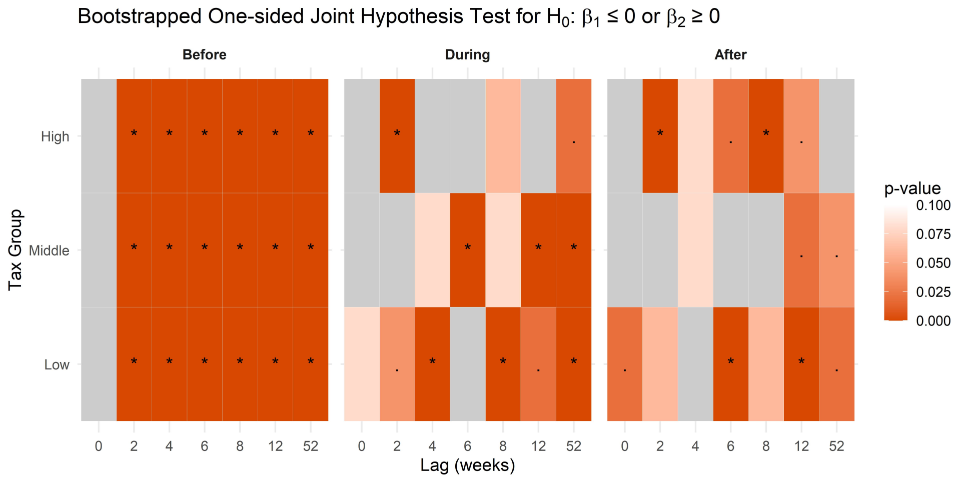

Figure 9: Test of Hypothesis 1 with a One-Sided Joint Hypothesis Test via Bootstrap Method across Tax Groups and Stages.

Notes: For each combination of tax group, stage, and lag, $*$ indicates significance at the 1% level and . at the 5% level. Deeper shades of orange indicate lower joint p-values. The test evaluates the null hypothesis $H_0 : \beta_1 \leq 0$ and/or $\beta_2 \geq 0$ against the alternative $H_A : \beta_1 > 0$ and $\beta_2 < 0$.

We show the results in Table 3 and as a plot with confidence intervals in Figure 8. For the comparison of non-linear combinations of coefficients across tax groups, we estimate the combined standard error of $Ships_g^* = -\frac{\beta_1^g}{2\beta_2^g}$ and use a bootstrap with 100 draws to obtain robust standard errors.

In all three periods, the high-tax group exhibits larger $Ships^*_{\text{High}}$ than the Low- and middle-tax groups. This indicates that the peak of the Laffer Curve for the high-tax group occurs at a higher number of ships. Our findings $Ships^*_{\text{High}} > Ships^*_{\text{Middle}}$ and $Ships^*_{\text{High}} > Ships^*_{\text{Low}}$ holds, and therefore, we reject the second null hypothesis.

In the Appendix, we also show the bootstrapped $Ships_g^*$ graphs for the period before Christian IV's reign from 1557-1596 (Figure 19) and the period 20 years after Christian IV's reign from 1648-1668 (Figure 20). The results for the second hypothesis hold the clearest for the period before Christian IV's reign. The high-tax group's optimal traffic threshold exceeds those of the low and middle groups. This indicates that under Christian IV, the high-tax group has been overtaxed relative to the others.

Table 3: Tax-Revenue-Maximizing Weekly Ship Volume (Ship*) by Stage and Tax Group

Tax-Revenue	Before Cristian IV 1557 - 1596			During Cristian IV 1596 - 1648			After Cristian IV 1648 - 1668		
Lag in weeks	**Low**	**Middle**	**High**	**Low**	**Middle**	**High**	**Low**	**Middle**	**High**
0	-142.87	-1106.20	-6534.02	66.83	-152.94	-3936.83	23.95	-65.55	-170.41
2	28.96	146.39	482.87	13.56	228.58	270.71	12.83	82.73	100.33
4	32.71	169.85	487.97	19.28	150.54	311.57	22.60	67.84	191.02
6	35.48	127.40	464.84	8.81	165.79	122.76	17.67	-574.31	94.25
8	26.01	136.35	476.45	19.73	153.99	135.34	13.28	61.90	141.44
10	33.10	173.20	436.60	16.94	89.12	39.17	327.88	50.55	365.71
12	26.56	207.56	440.29	15.53	97.40	135.81	11.66	43.98	141.40
52	29.17	209.87	443.19	19.94	172.37	309.93	12.06	44.18	69.72

Notes: All regressions include controls: `toll_over100`, `category_*`, `war_*`, and `week_*`.
The Tax Groups are: Low-Tax = Denmark and Sweden; Middle-Tax = Hanse and other German cities; High-Tax = Netherlands, United Kingdom and Others.

Results for Hypothesis 3: No Dynamic Behavioral Adjustment to Taxation

To test whether shipmasters adjusted differently to taxation after a year. We compare short-run (lag 12) and long-run (lag 52) responses across tax groups and historical stages. Using predicted values from the short- and long-run models, we construct Laffer Curves based on the margins estimates of the number of ships for the reign of Christian IV in Figure 10. The Laffer Curves for the stage before, and after Christian IV can be found in the Appendix (Figure 21 and Figure 22).

Sub-Hypothesis 1: No Differences in the Revenue-Maximizing Number of Ships between the Short- and the Long-Run

The main trend, for the stages during and after Christian IV's reign, is that the tax revenue-maximizing number of ships increases from the short-run (lag 12) to the long-run (lag 52). This suggests a lack of alternative trading routes, which keeps the number of ships higher than expected despite tax rate increases. These results contradict Buchanan and Lee (1982) hypothesis, that in the long-run the optimal tax rate shifts from T_0 to T_L^*. The stage before Christian IV, on the other hand, shows no difference between the lags, so that the Laffer Curves lie on top of each other, revealing no lagged taxation effects for any of the tax groups. An interpretation of this is that the time before Christian IV there was not as much newly introduced collections in the Sound Toll.

Sub-Hypothesis 2: No Differences in Laffer Curve Concavity between the Short- and the Long-Run

For the low-tax group, we observe a significant increase in curvature (i.e., the revenue function becomes more concave in the long-run), consistent with stronger taxpayer responsiveness of Sub-Hypothesis 2. This supports the idea that, over time, even lightly taxed merchants may adapt in ways that reduce taxable volume if rates rise. In contrast, the middle- and high-tax groups show no steepening of the Laffer Curve in the long-run. In fact, for the high-tax group, the curve flattens, implying that heavily taxed merchants either do not adjust significantly or have already adjusted in the short-run. These findings suggest that only the low-tax group exhibits long-run responsiveness in line with dynamic tax theory.

Overall, we find limited support for Buchanan and Lee (1982) dynamic Laffer Curve theory. While the low-tax group behaves as expected, the absence of leftward turning point shifts and lack of long-run concavity in the middle- and high-tax groups suggests that Christian IV's toll charges did not face behavioral change from the shipmasters over time. Especially, the high-tax group appears unresponsive to tax increases, likely due to a lack of substitutes in other transportation channels and the high relevance of trading with the Baltic regions. This was certainly the case for the Netherlands, which was the majority of the high-tax group. During much of the analysis period, the Netherlands was experiencing its Golden Age, particularly at sea (Harrison, 2024, p. 492), and the Sound may have supported this by facilitating the import of Baltic grain to feed the Dutch population (Veluwenkamp & Scheltjens, 2018, p. 1). However, a closer look at Table 3 reveals notable differences within the high-tax group, comparing the periods before and during Christian IV's reign. The optimal point is substantially higher in the earlier stage, suggesting that the tax increases under Christian IV led to diminishing returns.

Robustness Checks

We now outline several robustness checks that we considered to test the stability of our results. We considered stepwise inclusion of control variables to test whether our main estimates hold under more narrow specifications. While our baseline analysis uses inflation-adjusted tax revenues, we considered transforming our dependent variable into a logged percentage revenue growth to address the skewness of our data. However, the level-level regression form provided more stable and interpretable coefficients. Future robustness work could examine whether changes in tax levels affected the composition of traded

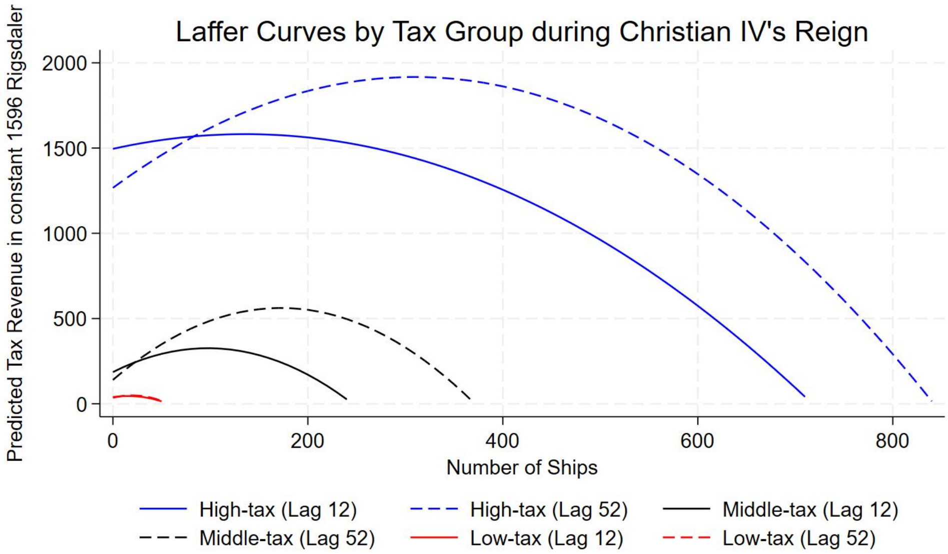

Figure 10: Short- and Long-Run Laffer Curves during the Reign of Christian IV (1596-1648)

goods, as shifts in commodity types might bias the tax revenue proxy if certain goods were taxed more heavily. We test the consistency of our results by estimating the model at a range of weekly lags, as shown in Table 2. For the test of dynamic behavior from Buchanan and Lee (1982), we use the most significant (β_1/β_2 combination) and logical approach when considering travel time from Ronnback (2012). This supports the choice of lag 12 (short-run) and lag 52 (long-run) for the analysis.

While our analysis uses a simplified tax group structure (Low-, Middle-, and High-Tax), historical evidence from Degn (2018, p. 142) supports a five-class system of taxation implementation at the Sound Toll. We described these classes briefly in the literature review section. Future work could reclassify tax groups accordingly and test whether Laffer Curve parameters change when using Degn (2018) Tax Hierarchies.

Another possible modeling approach would be to formalize Christian IV's tax rate-setting behavior as a game-theoretic optimization problem. We could use a Stackelberg leadership model originally developed from Von Stackelberg (2011) (English translation) in 1935. Using such a model, Christian IV would act as a strategic leader who anticipates merchant nations' reactions to tariff changes. In such a setting, he maximizes expected tax revenue subject to the constraints of the risk of retaliation or a decreasing number of ships passing the Sound if taxes are set too high. Expectations about the changing number of ships could be modeled using adaptive learning rules based on recent trends and seasonal cycles. Using such a formalization would enrich the theoretical structure of the analysis, but would require substantial modeling effort and strong assumptions about strategic behavior.

We test whether there might be reverse causality issues. For this, we examine whether current tax revenue and its square can explain the lagged number of ships, reversing the direction implied by Equation 5. We conduct a two-sided joint hypothesis test, as in Hypothesis 1, assessing whether $\delta > 0$ and $\delta < 0$, i.e., whether higher tax revenue leads to an increase in future shipping, but with diminishing returns. This specification allows us to test whether higher tax revenue today could affect the future number of ships. We estimate the following model:

$$\text{Ships}_{g,(w-l)} = \delta_0 + \delta_1 \cdot \text{Tax-Revenue}_{g,w} + \delta_2 \cdot \text{Tax-Revenue}^2_{g,w} + C_{g,w} + \varepsilon_{g,w} \tag{6}$$

The results provide strong evidence of reverse causality and are shown in Figure 23. The linear effect of tax revenue (δ_1) is often positive, while the squared effect (δ_2) is mostly negative. These findings suggest robust evidence of reverse causality, which further motivates the lag specification in our main model. To control for such reverse causality, Acemoglu et al. (2019) uses a model specification that could potentially be used for our research. We could adapt their model with autoregressive terms for lagged tax revenue. Such a specification can be written as:

$$Y_{g,w} = \beta_1 Ships_{gw} + \beta_2 Ships^2_{g,w} + \sum_{l=1}^{p} \gamma_k Y_{g,w-j} + \alpha_g + \delta_w + \epsilon_{g,w} \tag{7}$$

where $Y_{g,w}$ denotes tax revenue for group g in week w, $\text{Ships}_{g,w}$ is the number of ships passing the Sound Toll, α_g are group fixed effects, and δ_w are week fixed effects. The term $\sum_{j=1}^{p} \gamma_j Y_{g,w-j}$ captures tax revenue persistence over p lags. This formulation controls for persistent unobserved heterogeneity and temporal trends, and allows a better approximation of revenue dynamics using time series analysis. However, in our specific case, it is also well visible when looking at the data that the monarch could arbitrarily implement taxation deviations in certain weeks. This can be seen in the outliers in Figure 6 . Therefore, these deviations could disrupt the general trends and end up unreliable.

6 Discussion and Conclusions

By looking at early modern trade and taxation, our contribution provides evidence that Christian IV's Sound Toll policies revealed Laffer Curve effects in all tax groups. Further, it revealed signs of overtaxation in the high-tax group. Our contribution also provided an in-depth view of how short- and long-run behavioral responses to taxation changed tax revenues in early modern trade. More broadly, the findings underscore a classic tension between short-run revenue needs and long-run economic stability. Supporting Olson (1993) view, that rulers with narrow time horizons may adopt extractive policies that undermine economic welfare.

In addition, there are further considerations regarding the effect of an aggressive toll policy, various diplomatic tensions can escalate, and even a war threat can arise due to significant tax increases (Lockhart, 2007, p. 202). The policies affect important relationships with neighbors and allies, leading to long-term consequences and political losses. Discussed in section 3.1 Lockhart (2007, p. 203) stresses that the aggressive increases in the Sound Toll added up to the most severe diplomatic failing during the second half of Christian IV´s reign, turning previous great companions into unwilling, bitter enemies (Lockhart, 2007, p. 203). The effects of the sharp increases led the Sound Toll to adopt a softer attitude, and the Danish monarchy was unable to increase the Sound Toll as much (Degn, 2018, p.148). It seems plausible to assume that this had a long-run effect with a persistent increased sensitivity to the toll rates.

Interestingly, it can be implied that the tax collection imposed by the autocrat mirrors his view on long-run versus short-run. Furthermore, greed expressed in terms of increased military power and international prestige, as well as a desire for expanded territory, is often linked to a social cost for the autocrat, more than excessive abundance (Olson, 1993). This means that the autocrat not only faces a reduced income if excessively taxed, but he could also face severe social costs that can have long-run consequences according to Olson (1993). Therefore, our findings can be closely linked to the theory of Olson (1993) in particular, the encompassing interest of the autocrat, which was defined as the share of aggregated income the autocrat receives through taxation. Given our results, it can be argued that Christian IV rather had a short-term perspective while implementing a heavy taxation burden. This became apparent in the 1630s when the monarch needed short-term revenue. However, as mentioned above, the analysis demonstrated that the aftermath of Christian IV Sound Toll policies had severe consequences. Furthermore, Olson (1993) emphasizes that we know from history that the encompassing interest of the autocrat who collects taxes influences institutional and economic development.

When considering the limitations of our study, it is important to contemplate the years of our analysis that were turbulent, to say the least. Many wars occurred with severe consequences. During Christian IV's reign, the Thirty Years' War hampered institutional and economic progress. Harrison (2024, p. 489) emphasizes that the Thirty Years' War, above all, resulted in a drastic drop in the population. For early modern times, at least urban population growth is recurrently used as a proxy for economic development Acemoglu et al. (2005). Further, we know from Ljungqvist and Seim (2024) that at least the grain price stabilization is affected by war as a direct effect and then as an indirect effect via a population decrease. In which the grain price could arguably be considered as an indication of the overall food supply at the time. This should be taken into account when considering the estimations.

Using our tax rate proxy, the number of weekly ships in combination with the lagged tax revenue, the estimation is likely to be biased by the effect of trends within the tax rate. We are aware that the assumption of a stable tax rate within each tax group during each stage cannot hold. We show in our comparative analysis in section 4.1.1 that tax rates were substantially increased during the 1630s, so we have to assume that the variation of the number of ships reflects both the behavioral response to the tax rate as well as the changes in the tax rate itself. This weakens our causal interpretation of the Laffer Curve effects in our data significantly.

More controls than we have implemented are scarce, given the years we are analyzing. A crucial control variable possible to implement is distance. This could work as a control for the lag implementation to increase precision in estimating the information lags between the receipt of tax increases and the behavioral adaptation to them. Another way of gaining details of movements can be obtained through captain-level identification using the captain's name and career length. Raster (2024) uses this approach for his pioneering research. It could make our analysis more precise, by enabling us to see individual captains' behavior to tax rate increases.

The most feasible way to enhance the analysis is to obtain the values of the goods transported and, through them, obtain the percentage tax rates and re-estimate the Laffer Curve effects with the actual percentage tax rates. The analysis could lead to causal inference by constructing an instrumental variable approach, derived from exogenous trade cost shocks. Feyrer (2021) work on the 1967-1975 Suez Canal closure provides a useful example. His paper shows that higher trade costs led to significantly reduced trade volumes with a three- to four-year adjustment lag.

If import demand estimates over the period covered by the STRO could be derived, it would be possible to conduct a more refined analysis of the behavioral adjustments from taxation by incorporating elasticity estimates, similar to the approach in D. A. Irwin (1998). This could then be integrated with the classic contribution of Ramsey (1927) on the varying taxation of goods based on their demand elasticity. And reveal new findings, for the taxation of merchant ships. The STRO offers vast opportunities for further research on taxation, though additional data collection remains, for now, the primary constraint.

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A Data Appendix

The following section describes how we created our database:

We obtain the data from the Sound Toll Online Register (STRO). Under the download section, we downloaded the three main files (out of eight in total) of the database: Taxes/belastingen, Passages/doorvaarten, and Cargo/ladingen.

The names of many variables are written in Dutch, since the STRO has been created by the University of Groningen and the Frisian Historical and Literary Centre (Tresoar) at Leeuwarden. The content of the observations themselves is written in Danish, given the historical location of the customs office in Elsinore.

For our research, we rely on the explanation of the original structure of the STRO-tables, which can be found here. The key variable of the STRO-tables is $id - doorvaart$, which is the "unique identification number of the passage or registration serving as primary key" (STRO data explanation). It is also our key variable, which we use to identify toll revenues on a ship level.

We follow with an explanation of each of the three tables:

Passages/doorvaarten: Includes 1.9 million passages, including the shipmaster's name and origin, the exact date the ship passed the Sound, a total of tax paid in their respective currency, and tonnage of the vessel (non-numeric, rather descriptive, and not usable for our analysis).

Taxes/belastingen: Includes 2.9 million entries on the various taxes each ship had to pay in their respective currency for all different tolls. The main tolls levied in the Sound were the ship toll, cargo duty (lastetold or lastepenge), ad valorem duty, buoy fees (tøndepenge), and lantern fees (lygtepenge) (Degn, 2018, pp. 140–146).

Cargo/ladingen: 5.6 million entries of the various parcels a ship would transport, including the port of departure and the port of destination, the measuring unit and size, as well as the amount of the cargo duty in their respective currency, all for each parcel.

We merge the three tables in two steps:

(1) Merge of Passages/doorvaarten and cargo/ladingen.
(2) Merge of Passages/doorvaarten and taxes/belastingen.

We then append (1) and (2) to a masterfile totaling 8.6 million obs. and 81 variables.

Data Cleaning

In order to use the masterfile for our analysis, we had to circumvent the following difficulties:

(1) The Roman letters in the three amount variables

(Degn, 2018, p. 175) explains how the Roman letters were used and that they were applied from the beginning of bookkeeping in 1497 until their abolishment in 1666. We converted these with the *romantoarabic* Stata package from Cox (2011). Before running the package, we had to replace observations that included a +, which equals 0.5 added or subtracted to the value (depending on the position of the +), fraction values (e.g., 1/2 replaced with 0.5) and values that included four identical Roman letters to standard Roman notation (e.g., *iiii* to *iv*).

(2) Converting the values of the different currencies into the Rigsdaler coins

(Degn, 2018, pp. 150–156) gives us conversion ratios for the majority of currencies in which the Sound Toll was paid. According to him, the main currencies in which the Toll was paid were the Rigsdaler, Rose nobles, Gold guilders, Engelots, Ort, and Skilling. We also code the appearing coins Mark, Cruzado, Dukat, Milrese, Dobelt Pystoletter, Krone, Portugaløser and Henricus Nobel. We successfully converted from 1497 to 1670, ca. 95

percent, and after 1670 to 1857, ca. 99.9 percent, from the total of 8.6 million observations. Degn (2018, pp. 150–156) mentions that "Most of the other foreign coins are only seen from the 1560s to the 1590s.", hence the near complete conversion ratios from 1670 onward.

(3) Summing the three amount variables to the $total - daler$ variable

Given that we could find no explanation on how the researchers of the Soundtoll-Team calculated their totals, we compare them to our conversions. When tabulating their total, we find that the totals are only calculated from 1634. We therefore saw the need to compute our own totals and compared them afterwards to the given totals. After converging their totals, we plot the average amount per shipmaster and year in Figure 11. We see that the total of both the Soundtoll-Team and our coded totals are consistent over time. Given the unconsidered years before 1634 in the Soundtoll-Team totals, we continue using our own total daler calculations for the subsequent analysis on the Sound Toll.

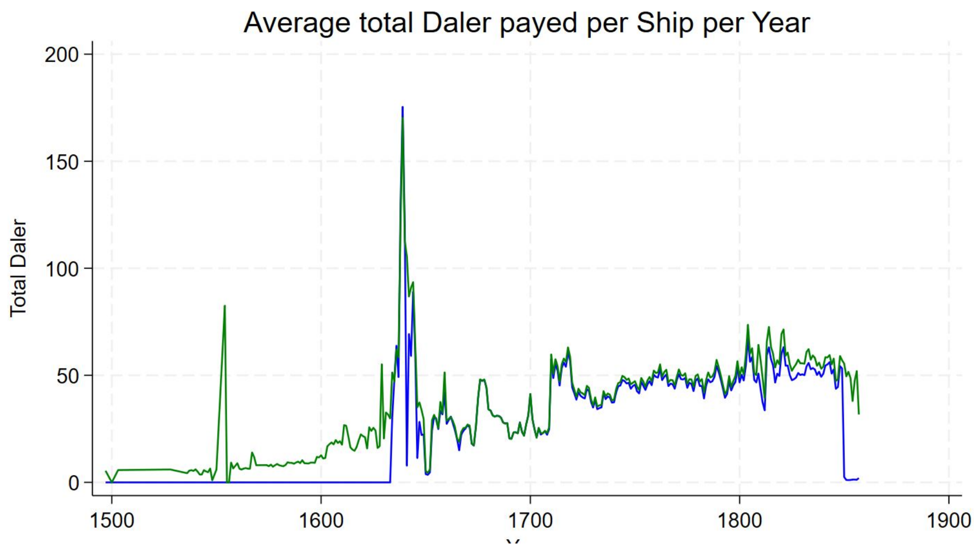


Figure 11: Line graph with own calculation in green and Soundtoll-Team calculation in blue (starting in the year 1634) of the average per year total rigsdaler paid for a ship passing the Sound.

(4) Standardizing the port names

The variables *schipper-plaatsnaam* (home port of the shipmaster), *van*(port of departure of the parcel), and *naar* (port of destination of the parcel) contained port names with various forms of writing. The bookkeepers varied in their writing of ports, f.e, Gothenburg (Göteborg) could be spelled as Goedtenb, Goettenborgh, Bottenborgh, Gaatenborg, Gaatenborig, etc.

Thankfully, the STRO data tables contain two tables which we can use for the standardization of port names:

(a) Places-Source contains 93.671 raw port names and their standardized equivalent
(b) Places-Standard contains 3.096 standardized port names, including the small and big regions the port belongs to, as well as lat. and long. data

From Places-Source, we create three separate do files that replace the various port names in *schipper-plaatsnaam*, *van*, and *naar* with their standardized equivalent. Furthermore, we merge the variables of Places-Standard with the home port of the shipmaster in our masterfile, i.e., we determine the nation of the shipmaster's home port. Duplicates of port names are a problem in this merge. This problem exists mainly between cities of the old and the new world (f.e, Boston, Bristol, Belfast, and Bangor). We have 92 duplicate port names that occur in different regions. Without an individual looking at each ship's commodities, it is impossible to determine if the ship came from one or the other duplicate port (f.e, Briston in the USA or Briston in England). Manually checking is, given our time constraint, no option, so we circumvent this issue through handpicking the city we think will have more trade, i.e. we make educated guesses and consider our research focus on the 17th century, where American-Baltic trade was still in it's infancy (Ronnback, 2009).

(5) Standardizing and categorizing the commodities

The commodities are highly unstructured. We find that occasionally, two different commodities are written together in one observation. The STRO does not provide additional tables on the different writings of the commodities, which differ from the port names. Veluwenkamp et al. (2021) writes about commodities in the STRO the following: "Sometimes the unit of measure and the quantity involve an amount of money, e.g., for 800 rd.

kramerie (for 800 rixdollars peddler's wares). The value per unit of the commodity is also sometimes recorded, for example: 156 fad stads viin à 52 rd. (156 casks of town wine at 52 rixdollars per cask). In this case, we enter the value per cask into the database as part of the commodity: 'stads viin à 52 rd.'..."

To standardize the goods, we use a fuzzy matching natural language processing (NLP) algorithm package, called *RapidFuzz*. Since such a matching procedure requires a significantly higher computing power, we run this part of our code in Python on *Google Colab*, where we are able to leverage *Google* server GPU. We acknowledge that using such a tool would be inappropriate for ethically sensitive data. However, since the STRO database is open source, we consider *Google Colab* as an acceptable tool.

When using a score matching threshold of 80, the algorithm matches 3,895,353 from 5,568,590 (i.e., 69.95 percent) of the total commodity observations. We run the code again, adapting the score matching threshold to 70, and obtain 4,589,262 matches (i.e., 82,41 percent) of the total commodity observations.

We manually revise the goodness of matches with a threshold of 70 and decide to use it for our continuing analysis, due to 693,909 more commodities matched. Afterwards, the commodities are matched via our key variable $id - doorvart$ with our masterfile.

We now have 1.550 unique standardized commodities, in their Danish original name, that were apparent in the Baltic trade. Using the (Incomplete) list of products that occur as cargoes in STRO for the English translation, we obtain a list of 1.226 unique standardized commodities. The reduced number is due to two or more Danish names for a commodity having the same meaning in English.

The next task is to classify the goods into different categories. We manually classify the English-translated 1.226 unique standardized commodities into 10 broad categories. Instead of categorizing into the Standard International Trade Classification (SITC), as seen in Raster (2024), we take a broader approach to analyze the composition changes of cargo on ships and to use the commodity categories as control variables in our regression setup. During the translation and categorization process, we lose (4,589,262 - 4,212,914 =) 376,348 commodities. We manually revise (4,511,088 - 4,212,914 =) 298,174 unmatched commodities and assign them to a category. The remaining (4,589,262 - 4,511,088=)78,174 commodities are only recognizable through an extended search, which we will not focus on.

(6) Standardizing the Toll Types

We standardized the toll types recorded in the dataset. For this, we homogenized spelling and capitalization inconsistencies across toll types. Furthermore, we merge City-Gods into one toll type. City gods were charged for goods from various cities. For more information, see Table 8.

(7) Deflating the Toll Rates

We account for changes in the price level over time and express toll revenues in real terms by deflating nominal values using a historical inflation index constructed by Abildgren (2010). The yearly inflation rates (in percentage terms) were obtained from Kim Abildgren's website, covering the period from 1500 to 1857. To create the deflator, we take the cumulative sum of the logged inflation rates and take the exponent afterwards to generate a consistent price index over time. This index is then normalized to 1 in the base year 1596, marking the coronation of Christian IV.

Using this deflator, we convert nominal toll revenue $total - daler$ into real toll revenue $real - daler$, adjusting for inflation and capturing the true purchasing power of the collected tolls. This step ensures that our revenue estimates reflect genuine changes in economic activity, toll policy, and maritime traffic, rather than nominal price fluctuations.

We are aware of the limitations of inflation rates in Denmark. Abildgren (2010) states that he used prices on rye and barley from 1552-1712 and for 1600-1660 on rye, barley, and oats. Before 1552, there were only sporadic prices available, so the author interpolated prices during this time. From 1712 onward, a more sophisticated consumer price index was used.

B History of the Sound Toll

Year	Event
1470	Cargo toll introduced, due to privileges not collected from Danes, Norwegians, Swedes, or the Hanseatic League.
1497–1501	Sound Toll began as a ship toll... Dutch shipmasters sometimes paid 2 nobles for larger ships, and a few paid 3.
1507–1509	Differentiated ship toll established: 1 noble for ballast ships, 2 nobles for small loaded ships, and 3 nobles for ships carrying more than 100 lasts.
1519	Cargo duty reintroduced... Buoy fees (tøndepenge) introduced by Mother Sigbrit.
1523	Fall of King Christian II led to the abolition of the cargo duty, but it was reinstated in 1567.
1534–1536	Salt toll introduced after the Counts' War. Six barrels of toll salt collected per ship, with value subtracted from the toll.
1560	Stricter toll policies were introduced due to concerns about fraud. A tariff table was created.
1560	Introduction of hierarchical classification of nations: - First-class: Denmark, Norway, and Sweden - Second-class: Eastern Hanseatic cities - Third-class: Western Hanseatic cities and the Netherlands - Fourth-class: England, Scotland, France, and Emden
1560	Principle of "not a free ship, no free commodities" applied.
1566	Increase in ad valorem duty introduced... dessert wine, French wine, Rhine wine, etc.
1567	New cargo toll: 1 daler per last of commodities, ½ for ballast ships.
1568	Toll temporarily abolished for the Netherlands, reintroduced in 1571.
1583	Lübeck lost toll exemption, placed in the same class as the Dutch.
1588	Ballast toll abolished due to complaints.
1622	New harbor charges introduced. Revenue is used in Elsinore.
1625–1629	Danish-German Emperor War increased revenue needs. "Defence Toll" was introduced in 1627.
1627	Royal decree officially established the Defence Toll.
1630s	King Christian IV increased the Sound Toll amid council opposition.
1638	Return to higher tolls and multiple toll increases.
1642–1643	Toll system adjusted due to Dutch pressure.
1645	Christianopel Treaty granted Dutch ships privileges and lower tolls.
1651	Frederick III stated Dutch ships shouldn't pay more than voluntarily offered.
1720	Peace of Frederiksborg. Sweden last nation to pay toll.
1857	Final Commutation of the Sound Toll.

Table 4: Timeline of the Introduction and Abolition of the Various Tolls during 1470–1857. Source: (Degn, 2018, pp. 139-163)

Table 5: Inflation in Denmark during selected War Periods

Period	**War**	**Average[a]**	**Max**	**Min**
		Per cent per annum		
1563–1570	The Nordic Seven Years War	2.3	27.8	-17.5
1611–1613	The Kalmar War	-1.3	14.1	-10.9
1625–1629	The Kaiser War	1.5	46.7	-34.0
1643–1645	The Torstensson War	-6.0	2.5	-20.3
1657–1660	The Karl Gustav War	13.2	74.7	-31.5
1675–1679	The Scania War	-5.9	1.1	-10.9
1709–1720	The Great Nordic War	-0.4	83.6	-42.2
1756–1763	The Prussian Seven Years' War	4.1	17.7	-12.2
1808–1813	The Napoleonic Wars	77.5	311.2	12.5
1848–1851	The First Schleswig War	-3.7	2.4	-11.0

[a] The average inflation rates are calculated as compound growth rates.
Source: (Abildgren, 2010)

C Further Figures

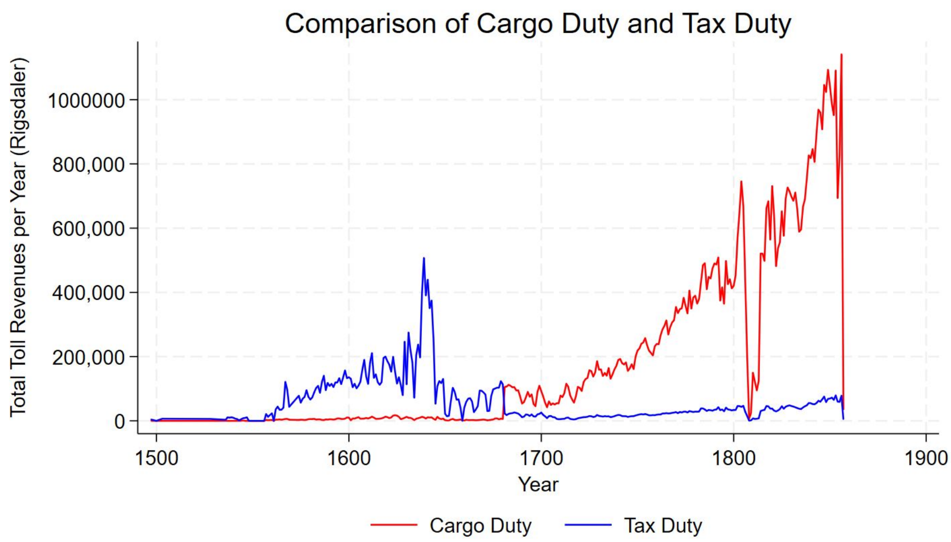


Figure 12: Comparison of Cargo- vs. Tax- Duty over Time

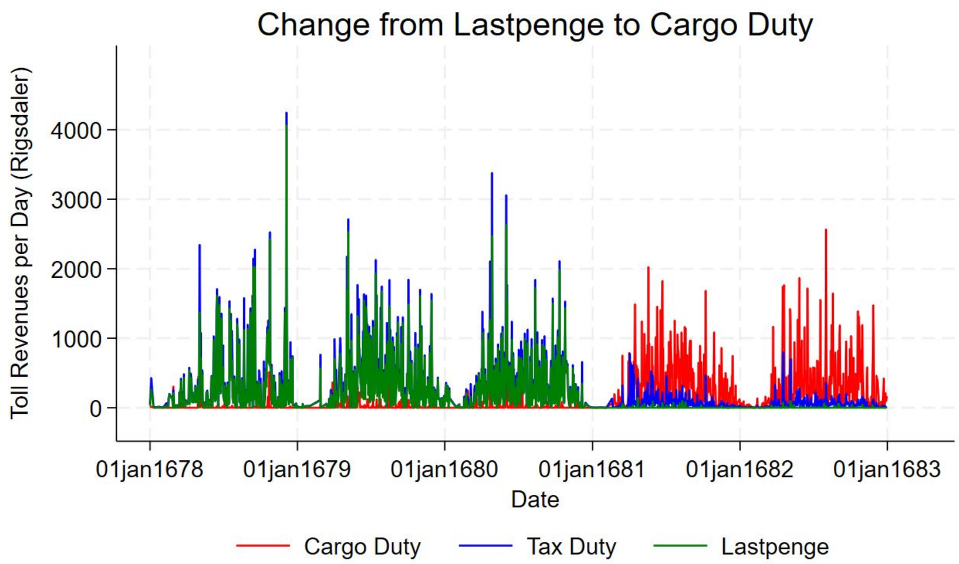
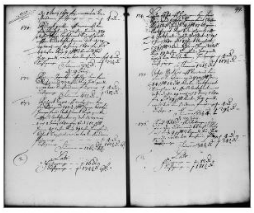


Figure 13: Change from Lastpenge (the main component of the Tax Duty until 1680) to Cargo Duty in a 5-Year window from 1678 to 1682

Passage



Sonttolregisters-141_0070.jpg

ID	713128
Date	19-6-1680
Passage	173
Shipmaster	Rinert Aages from Molquern
Patronymic	
Section	Hollandske, fra Østersøen
Register	Indtægt (Christian Falk og Anders Nielsen) 1680
Tonnage	

Cargo

Depart.	Dest.	Amount	Unit	Commodity	Toll
1. Riga	Amsterdam	143	Skippund	Hamp	
2. Riga	Amsterdam	600	Te.	Hampefrøe	
3. Riga	Amsterdam	512	Skippund	Hamp	
4. Riga	Amsterdam	40	Læster	Rug	
5. Riga	Amsterdam	19	Læster	Hampefrøe	
6. Riga	Amsterdam	6	Shock	Clapholt	
				Fyrpenge	4 Daler
				Lastpenge	112 1/2 Daler 6 Skilling
				Total	116 1/2 Daler 6 Skilling

Figure 14: Passage Entry (ID) 713129 with Lastpenge and no Cargo Duty from STRO
.

Passage

Sonttolregisters-142_0063.jpg

ID	719739
Date	16-8-1681
Passage	447
Shipmaster	Tenis Acherman from Lantzmer
Patronymic	Jannssen
Section	Hollandske, Westen af
Register	Indtægt (Anders Nielsen og Christian Falk) 1681
Tonnage	

Cargo

Depart.	Dest.	Amount	Unit	Commodity	Toll
1. Amsterd.	Kønnsberg	19	Lester	Sild	9 1/2 Daler
2. Amsterd.	Kønnsberg	8 1/2	Piber	Olie	6 Daler 18 Skilling
3. Amsterd.	Kønnsberg	5	Piber	Syltid lemoner	1 1/2 Daler 18 Skilling
4. Amsterd.	Kønnsberg	2000	Pund	Sebe rossiner oh sucher	3 1/2 Daler 12 Skilling
5. Amsterd.	Kønnsberg	80	Ste.	Catundug	3 Daler 6 Skilling
6. Amsterd.	Kønnsberg	800	Pund	Bomuld	3 Daler
7. Amsterd.	Kønnsberg	12	Pund	Silche	2 1/2 Ort
8. Amsterd.	Kønnsberg	12	Ste.	Klede	1 Daler 12 Skilling
9. Amsterd.	Kønnsberg	48	Ste.	Uldennstof	1 Daler 12 Skilling
10. Amsterd.	Kønnsberg	1500	Dr.	Crameri	9 Daler 18 Skilling
11. Amsterd.	Kønnsberg	8 1/2	Fade	Frantz vin a 52 Rd.	
					40 Daler 6 Skilling
				Fyrpenge	4 Daler
				30 Penge	15 Daler
				Total	59 Daler 6 Skilling

Figure 15: Passage Entry (ID) 719739 with Cargo Duty and no Lastpenge from STRO
.

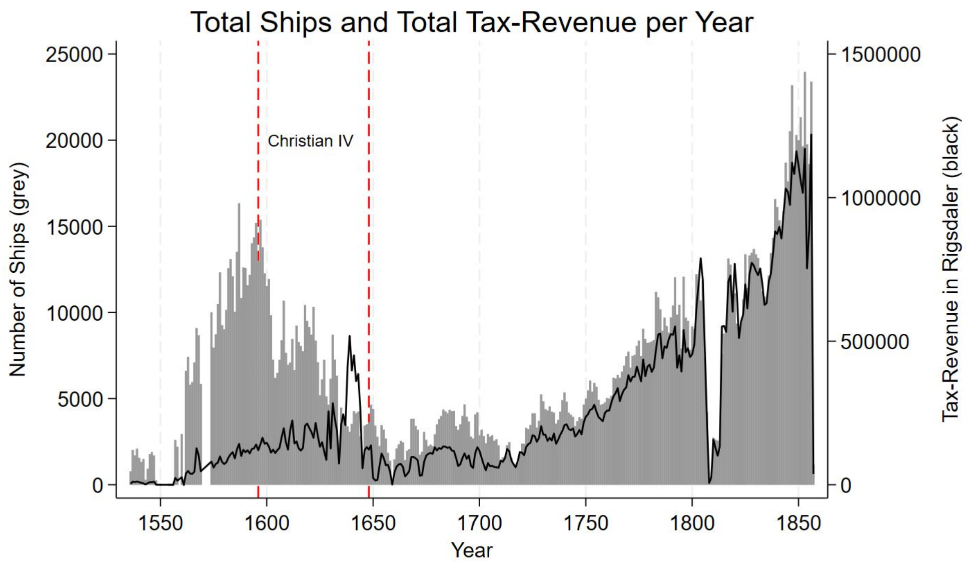


Figure 16: Total Ships and Nominal Total Tax-Revenue over Time

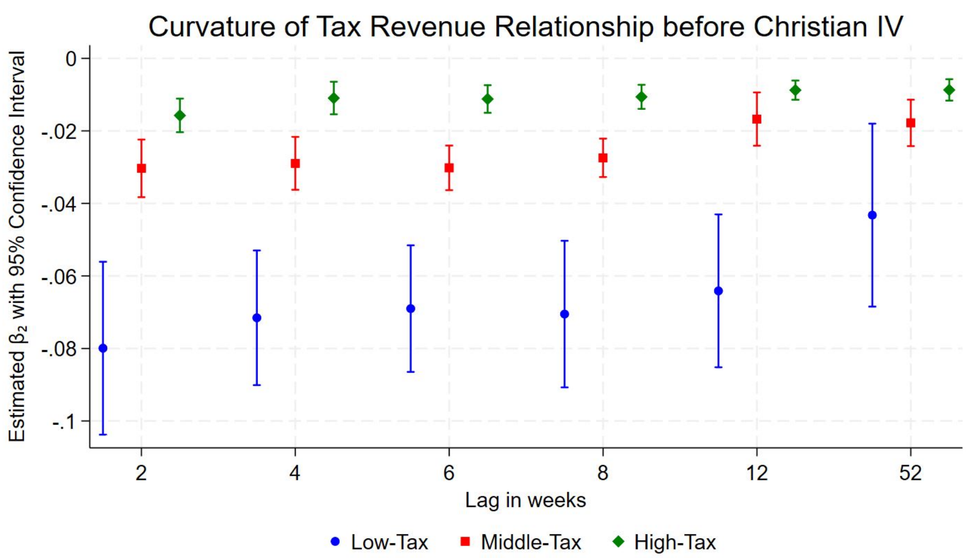


Figure 17: β_2 Coefficient of $Ships^2$ per Lag before the Reign of Christian IV (1557-1596) with robust 95% Confidence Intervals

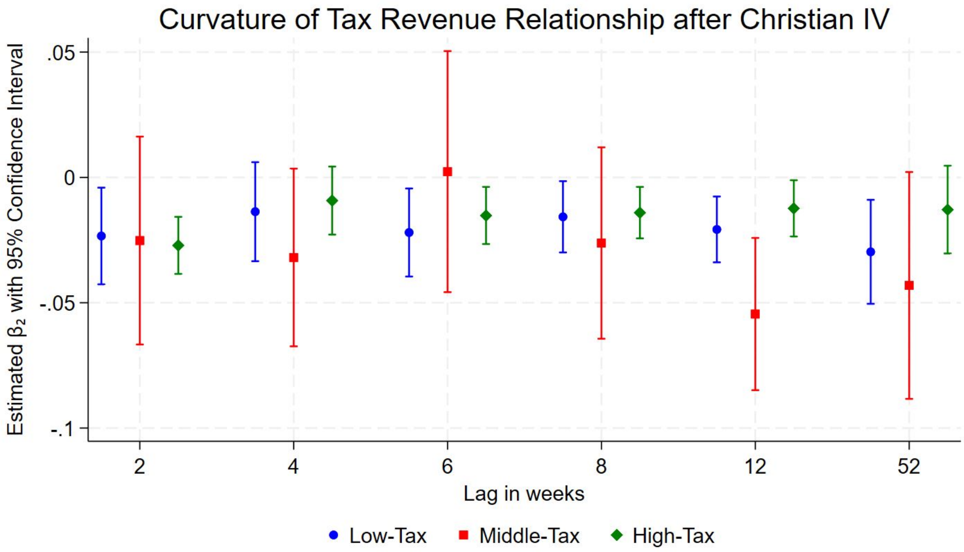


Figure 18: β_2 Coefficient of $Ships^2$ per Lag after the Reign of Christian IV (1648-1668) with robust 95% Confidence Intervals

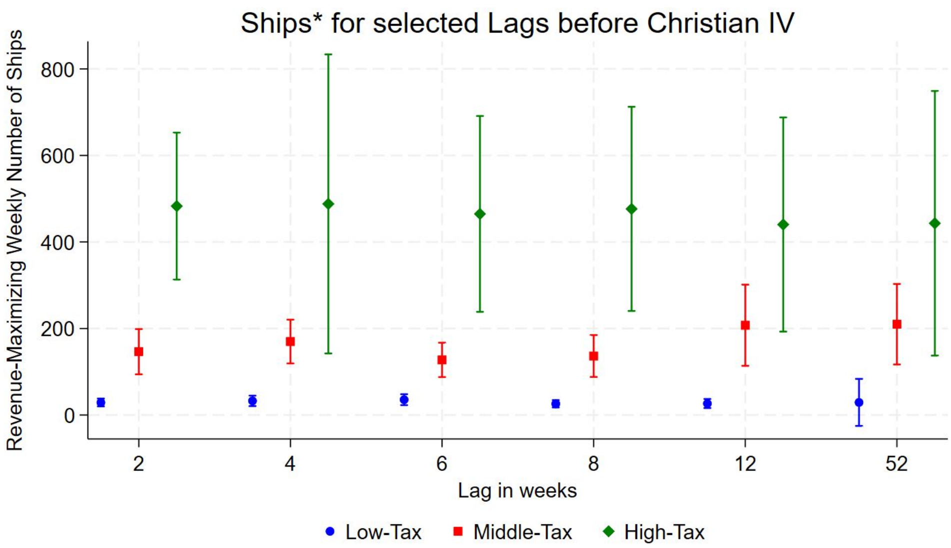


Figure 19: Optimal Weekly Number of Ships per Lag before the Reign of Christian IV (1557-1596) with bootstrapped robust 95% Confidence Intervals

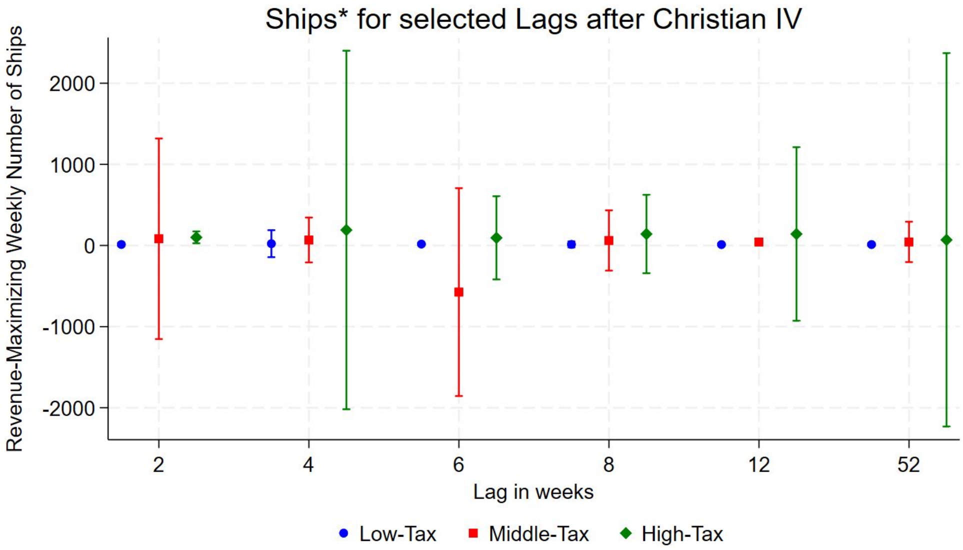


Figure 20: Optimal Weekly Number of Ships per Lag after the Reign of Christian IV (1648-1668) with bootstrapped robust 95% Confidence Intervals

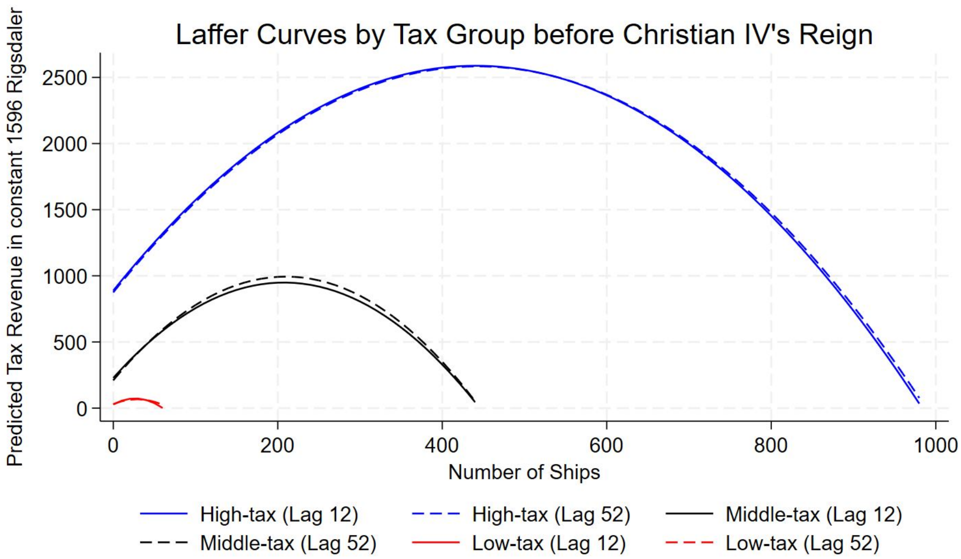


Figure 21: Short- and Long-Run Laffer Curves before the Reign of Christian IV (1557-1596)

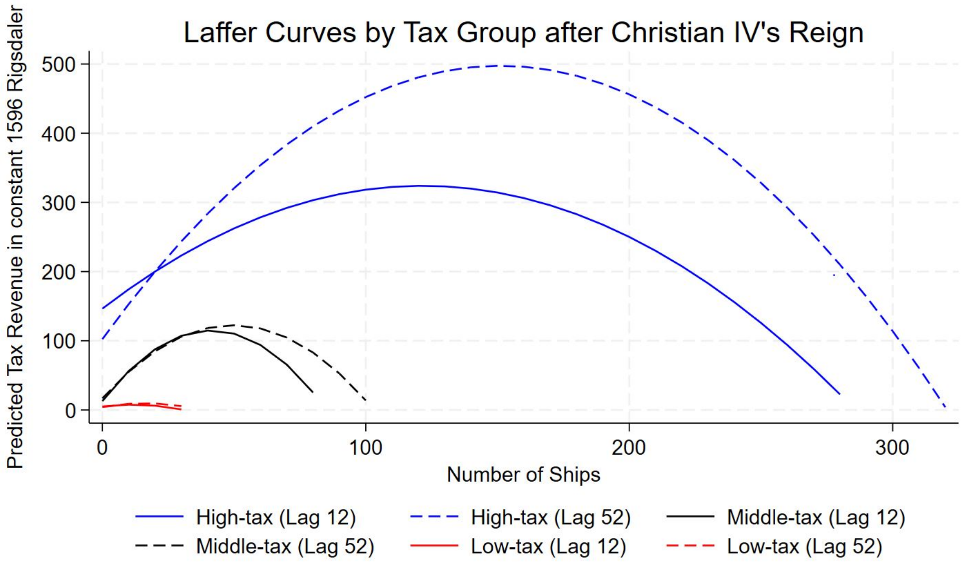


Figure 22: Short- and Long-Run Laffer Curves after the Reign of Christian IV (1648-1668)

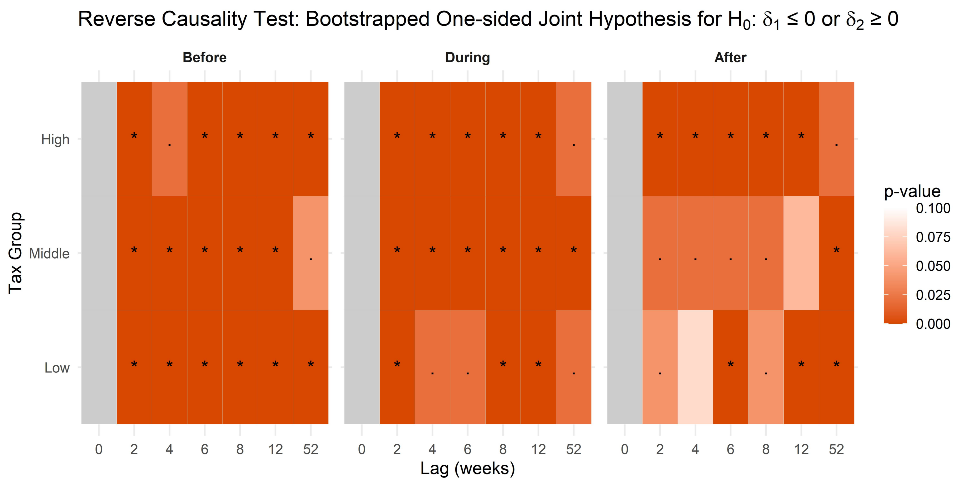


Figure 23: Reverse Causality Test of Hypothesis 1 on Equation 6 with a One-Sided Joint Hypothesis Test via Bootstrap Method across Tax Groups and Stages.

Notes: For each combination of tax group, stage, and lag, $*$ indicates significance at the 1% level and . at the 5% level. Deeper shades of orange indicate lower joint p-values. The test evaluates the null hypothesis $H_0 : \delta_1 \leq 0$ and/or $\delta_2 \geq 0$ against the alternative $H_A : \delta_1 > 0$ and $\delta_2 < 0$.

D Further Tables

Table 6: Deflated Summary Statistics of the Top 10 Toll Types

			Per Toll paid			
Stage	**Toll Type**	**Total**	**Mean**	**SD**	**Min**	**Max**
Before Christian IV (1497–1596)						
	Lastpenge	2,009,585	27.34	29.33	0	721.09
	Under 100 Lester	554,310	12.47	3.43	0	73.17
	Skibstold	462,300	7.84	9.60	0	2034.26
	100 Penge	312,792	23.74	36.60	0	1061.15
	Cargo Duty	220,895	0.35	4.67	0	571.55
	City Gods	143,551	8.48	4.01	0	53.33
	Lastpenge Ballast	89,402	10.96	5.75	0	149.68
	Over 100 Lester	86,794	22.05	6.96	0	39.64
	Fyrpenge	57,599	0.65	5.06	0	1472.48
	Under 30 Lester	56,469	8.07	1.92	0	27.08
	...					
	Rest (43)	182,300				
Reign of Christian IV (1596–1648)						
	Lastpenge	2,852,325	19.23	18.74	0	866.23
	Forhøjelsen	408,467	13.16	20.17	0	160.59
	Under 100 Lester	335,932	6.43	9.10	0	2000.00
	100 Penge	332,236	16.37	38.11	0	1723.19
	Cargo Duty	261,873	0.28	3.94	0	559.29
	Over 100 Lester	229,121	5.41	2.65	0	155.39
	Skibstold	183,159	3.33	1.84	0	178.14
	Defension	110,443	2.70	2.67	0	83.26
	Fyrpenge	101,288	0.63	1.18	0	246.49
	Endt	68,590	6.59	4.79	0	68.68
	...					
	Rest (61)	335,411				
After Christian IV (1648–1857)						
	Cargo Duty	505,379	0.13	0.83	0	945.55
	Lastpenge	181,876	5.55	5.72	0	205.68
	Skibstold	129,424	14.20	12.39	0	146.85
	Over 100 Lester	128,385	58.81	12.83	0	90.00
	Under 100 Lester	112,449	38.67	9.19	0	73.37
	Told	81,704	34.11	29.67	0	653.67
	Fyrpenge	58,775	0.04	0.12	0	74.74
	30 Penge	19,067	2.71	4.42	0	115.38
	City Gods	13,114	0.58	3.72	0	48.91
	Gode bref	6,223	12.25	8.35	0	22.50
	...					
	Rest (67)	14,254				

Source: Own summation based on Sound Toll Records Online (STRO).
Values in constant 1596 Rigsdaler. Toll types reflect cleaned and standardized entries.
"Rest" includes all toll types outside the Top 10 by total revenue in each stage.

Table 7: Summary Statistics of the Top 10 Toll Types

			Per Toll paid			
Stage	**Toll Type**	**Total**	**Mean**	**SD**	**Min**	**Max**
Before Christian IV (1497 - 1596)						
	Lastpenge	1,451,563	19.75	19.68	0	529.50
	Under 100 Lester	376,851	8.48	1.31	0	40.50
	Skibstold	289,524	4.91	8.53	0	2000.00
	100 Penge	215,727	16.37	27.42	0	930.16
	Cargo Duty	144,860	0.23	3.07	0	550.00
	City Gods	96,334	5.69	2.73	0	45.38
	Lastpenge Ballast	63,250	7.75	4.04	0	100.88
	Over 100 Lester	44,907	11.41	2.69	0	18.00
	Under 30 Lester	38,307	5.47	0.87	0	11.50
	Fyrpenge	36,490	0.41	2.33	0	670.14
	...	...				
	Rest (43)	120,229				
During Christian IV (1596 - 1648)						
	Lastpenge	5,460,070	36.81	37.09	0	1027.00
	Forhøjelsen	1,252,123	40.34	61.78	0	488.25
	100 Penge	597,624	29.44	54.18	0	2043.02
	Cargo Duty	501,007	0.54	6.69	0	810.00
	Over 100 Lester	500,414	11.82	3.44	0	473.25
	Under 100 Lester	475,805	9.11	9.04	0	2000.00
	Defension	339,093	8.29	8.19	0	253.00
	Skibstold	276,697	5.03	2.87	0	204.50
	Fyrpenge	247,726	1.53	2.81	0	333.41
	Endt	212,397	20.39	14.79	0	210.00
	...	...				
	Rest (61)	687,785				
After Christian IV (1648 - 1857)						
	Cargo Duty	62,688,423	15.70	46.72	0	1000.18
	Fyrpenge	4,306,870	3.23	1.44	0	634.19
	Lastpenge	1,347,210	41.11	40.97	0	1000.00
	30 Penge	289,057	41.07	61.72	0.13	932.00
	City Gods	121,183	5.38	2.24	0	74.58
	Vide Folio	110,484	33.88	95.81	0	982.13
	Ucertif. Ladning	60,724	4.95	1.09	0.25	28.25
	Skibstold	31,614	3.47	3.28	0	95.00
	Over 100 Lester	29,362	13.45	0.62	0	18.00
	Under 100 Lester	27,027	9.29	1.31	0	18.00
	...	...				
	Rest (67)	174,762				

Source: Own summation made from the STRO
All values in nominal Rigsdaler, unadjusted for inflation. Toll types reflect cleaned and standardized entries. "Rest" includes all toll types outside the Top 10 by total revenue in each stage.

Table 8: Description of the Main Toll Types

Toll Name (in English, then Danish occurence in Data)	**Description**
Ad-Valorem Duty (30 – *Penge*) (*100-Penge*)	1/30th or 1/100th of the value of the good as a Duty
Cargo-Duty (*Lastpenge*)	In our data, Cargo Duty is recorded separately from Lastpenge. When tolls were registered as Lastpenge, it was not possible to determine the toll amount applied to individual goods. Starting in 1681, Lastpenge was replaced by Cargo Duty—though it remains unclear whether this change was made by the original Danish bookkeepers or by the Sound Toll Records team. This transition enabled a more detailed breakdown of tolls by specific goods.
Lighthouse Money *Fyrpenge*	Toll to maintain the Lighthouses around the Toll
City-Gods	Tolls for goods from various cities
Defense toll *Defension*	Defense fees
Buoy fees (*tøndepenge*)	For "the laying of a buoy with a bell on Trindelen Reef near the island of Læsø" (Degn, 2018, p. 143).
Premium / Agio (*Forhøjelsen*)	Increase Toll in certain years during the 1620s - 1630s in the name of Christian IV.
Rebates (*Vide Folio*)	"(...) corrections of or additions to earlier entries. (...)" (A concise source criticism of STRO database). We omit these rebates from our analysis, acknowledging that a more precise approach would involve accounting and deducting them accordingly.
Weight Toll *Over/Under 30/100 L.*	Toll according to the cargo capacity of the ship

Source: (Degn, 2018, pp. 139–163), STRO Method Manual and A concise source criticism of STRO database

Table 9: Deflated Summary Statistics by Commodity Categories Toll

Stage	Category	Entries	Total	Per Comm. Category Paid Mean	SD	Min	Max
Before Christian IV (1497–1596)							
	Other	121,693					
	Metals & Minerals	32,933					
	Alcohol & Beverages	3,996					
	Textiles & Clothing	31,554					
	Ballast	49,955					
	Grain & Food	105,886					
	Livestock & Animal Products	26,764					
	Spices & Luxury Goods	3,746					
	Wood & Timber Products	52,700					
	Weapons	249					
Reign of Christian IV (1596–1648)							
	Other	230,854					
	Alcohol & Beverages	16,641					
	Grain & Food	117,244					
	Textiles & Clothing	68,137					
	Livestock & Animal Products	42,595					
	Wood & Timber Products	74,836					
	Metals & Minerals	54,082					
	Spices & Luxury Goods	26,267					
	Ballast	43,101					
	Weapons	1,000					
After Christian IV (1648–1857)							
	Other	1,052,263	143,855	0.137	0.476	0	111.30
	Grain & Food	506,609	83,664	0.165	0.502	0	41.08
	Metals & Minerals	479,980	54,289	0.113	0.386	0	14.53
	Textiles & Clothing	254,078	33,406	0.131	0.481	0	138.38
	Spices & Luxury Goods	122,477	32,588	0.266	0.904	0	24.70
	Alcohol & Beverages	128,261	30,206	0.236	0.979	0	122.05
	Wood & Timber Products	551,043	22,468	0.041	0.123	0	9.69
	Livestock & Animal Products	74,806	12,056	0.161	0.932	0	142.68
	Weapons	15,126	795	0.053	0.135	0	5.24
	Ballast	280,621	47	0.0002	0.014	0	5.68

Source: Own summation based on the Sound Toll Records Online (STRO).
Note: Toll charges for individual commodities were only recorded separately from 1681 onward. Prior to that, all commodity duties were aggregated under Lastpenge (cargo duty), which is included in total tax entries. Hence, values for the stages Before Christian IV and Reign of Christian IV are left blank. All values are in constant 1596 Rigsdaler.

Table 10: Summary Statistics by Commodity Categories Toll

				Per Commodity Category Paid			
Stage	**Category**	**Entries**	**Total**	**Mean**	**SD**	**Min**	**Max**
Before Christian IV (1497–1596)							
	Other	121,693					
	Metals & Minerals	32,933					
	Alcohol & Beverages	3,996					
	Textiles & Clothing	31,554					
	Ballast	49,955					
	Grain & Food	105,886					
	Livestock & Animal Products	26,764					
	Spices & Luxury Goods	3,746					
	Wood & Timber Products	52,700					
	Weapons	249					
Reign of Christian IV (1596–1648)							
	Other	211,669					
	Alcohol & Beverages	14,322					
	Grain & Food	106,302					
	Textiles & Clothing	59,203					
	Wood & Timber Products	70,749					
	Metals & Minerals	47,593					
	Livestock & Animal Products	38,036					
	Spices & Luxury Goods	23,651					
	Ballast	38,293					
	Weapons	904					
After Christian IV (1648–1857)							
	Other	1,052,263	16,838,112	16.00	36.97	0	991.00
	Grain & Food	506,609	10,057,170	19.85	34.25	0	933.01
	Spices & Luxury Goods	122,477	7,678,891	62.70	139.76	0	1,000.09
	Metals & Minerals	479,980	7,199,672	15.00	36.09	0	1,000.00
	Textiles & Clothing	254,078	6,342,283	24.96	72.01	0	1,000.18
	Alcohol & Beverages	128,261	4,002,404	31.21	79.38	0	1,000.06
	Wood & Timber Products	551,043	3,452,408	6.27	14.88	0	940.69
	Livestock & Animal Products	74,806	616,568	8.24	24.28	0	708.38
	Weapons	15,126	83,448	5.52	13.49	0	500.00
	Ballast	280,621	9,046	0.03	0.81	0	107.17

Source: Own summation based on the Sound Toll Records Online (STRO).
Note: Toll charges for individual commodities were only recorded separately from 1681 onward. Prior to that, all commodity duties were aggregated under Lastpenge (cargo duty), which is included in total tax entries. Hence, values for the stages Before Christian IV and Reign of Christian IV are left blank. All toll values are nominal Rigsdaler, unadjusted for inflation.

Table 11: Deflated Summary Statistics on the Nations Paying the Sound Toll

				Per Ship paid			
Stage	**Flag**	**Ships**	**Total**	**Mean**	**SD**	**Min**	**Max**
Before Christian IV (1497–1596)							
	Netherlands	190,516	2,359,312	12.38	16.37	0	1,472.48
	Hanse	56,308	591,276	10.50	23.79	0	670.50
	UK	22,460	472,235	21.03	34.85	0	1,066.85
	Other German	29,390	320,498	10.91	12.89	0	287.46
	Other	8,652	135,255	15.63	36.37	0	2,045.12
	Denmark-Norway	12,057	73,770	6.12	11.90	0	241.41
	Sweden	3,806	15,007	3.94	8.52	0	128.44
Reign of Christian IV (1596–1648)							
	Netherlands	230,195	3,336,180	14.49	20.84	0	2,000.50
	UK	20,632	603,986	29.27	53.26	0	1,796.15
	Hanse	51,053	494,640	9.69	22.75	0	1,847.42
	Other German	13,595	130,310	9.59	10.90	0	148.18
	Other	7,911	126,899	16.04	21.87	0	313.09
	Denmark-Norway	19,841	90,247	4.55	11.59	0	345.88
	Sweden	7,986	22,609	2.83	8.93	0	145.22
After Christian IV (1648–1857)							
	Netherlands	258,603	441,680	1.71	4.29	0	189.53
	UK	328,934	168,961	0.51	1.57	0	79.35
	Hanse	201,950	128,707	0.64	2.48	0	181.18
	Sweden	189,156	41,326	0.22	0.76	0	58.85
	Denmark-Norway	242,428	35,633	0.15	0.75	0	51.14
	Other	40,888	29,455	0.72	2.83	0	174.15
	Other German	121,695	22,582	0.19	0.92	0	71.03

Source: Own calculations based on Sound Toll Records Online (STRO).
Ships are defined as ship entries in the STRO.
All values in constant 1596 Rigsdaler.

Table 12: Summary Statistics on the Nations Paying the Sound Toll

				Per Ship paid			
Stage	**Flag**	**Ships**	**Total**	**Mean**	**SD**	**Min**	**Max**
Before Christian IV (1497–1596)							
	Netherlands	190,516	1,624,087	8.52	10.71	0	670.14
	Hanse	56,308	404,629	7.19	17.02	0	424.00
	UK	22,460	332,559	14.81	25.64	0	935.16
	Other German	29,390	223,476	7.60	8.60	0	180.00
	Other	8,652	88,994	10.29	27.50	0	2,010.67
	Denmark & Norway	12,057	56,035	4.65	9.20	0	179.88
	Sweden	3,806	11,178	2.94	6.70	0	90.66
Reign of Christian IV (1596–1648)							
	Netherlands	230,195	6,587,757	28.62	53.83	0	2,004.50
	UK	20,632	1,179,451	57.17	103.89	0	2,129.52
	Hanse	51,053	980,444	19.20	47.94	0	2,027.19
	Other	7,911	248,505	31.41	55.65	0	853.47
	Other German	13,595	187,686	13.81	20.28	0	467.79
	Denmark & Norway	19,841	183,130	9.23	27.68	0	704.96
	Sweden	7,986	56,978	7.13	25.08	0	442.41
After Christian IV (1648–1857)							
	UK	328,934	21,418,589	65.12	123.55	0	2,789.06
	Hanse	201,950	11,268,173	55.80	102.83	0	1,721.69
	Netherlands	258,603	10,613,377	41.04	58.06	0	1,310.94
	Sweden	189,156	6,582,915	34.80	78.20	0	2,174.59
	Denmark & Norway	242,428	5,169,683	21.32	60.84	0	1,921.34
	Other German	121,695	4,417,485	36.30	63.30	0	1,526.53
	Other	40,888	3,917,886	95.82	162.63	0	2,610.89

Source: Own summation based on Sound Toll Records Online (STRO).
Ships are defined as ship entries in the STRO. All values in nominal Rigsdaler, unadjusted for inflation.

Table 13: Yearly Inflation Rates

Year	Inflation	Year	Inflation	Year	Inflation	Year	Inflation	Year	Inflation
1503	1.734707	1574	0.813978	1645	1.493578	1716	-0.012950	1787	1.864974
1504	1.554002	1575	0.569288	1646	2.080114	1717	-0.506577	1788	1.579261
1505	1.369300	1576	0.440146	1647	2.607223	1718	-1.022235	1789	1.347968
1506	1.174411	1577	0.442548	1648	2.960093	1719	-1.515287	1790	1.127399
1507	0.962802	1578	0.542985	1649	2.933918	1720	-1.947629	1791	0.895743
1508	0.729548	1579	0.798568	1650	2.554210	1721	-2.301573	1792	0.688626
1509	0.473442	1580	1.043722	1651	2.111134	1722	-2.462915	1793	0.469707
1510	0.199330	1581	1.269808	1652	1.873737	1723	-2.393767	1794	0.222517
1511	-0.079323	1582	1.505855	1653	1.963535	1724	-2.130948	1795	-0.027608
1512	-0.337701	1583	1.791354	1654	2.659359	1725	-1.728569	1796	-0.262918
1513	-0.559734	1584	2.151081	1655	3.825616	1726	-1.255779	1797	-0.449729
1514	-0.735522	1585	2.527359	1656	5.066427	1727	-0.798770	1798	-0.429367
1515	-0.859109	1586	2.929552	1657	6.148891	1728	-0.495200	1799	-0.074921
1516	-0.926728	1587	3.301866	1658	7.016193	1729	-0.419243	1800	0.750994
1517	-0.935565	1588	3.673021	1659	7.562224	1730	-0.529256	1801	2.186559
1518	-0.883081	1589	4.018515	1660	7.295721	1731	-0.715039	1802	4.462961
1519	-0.766928	1590	4.152115	1661	6.007008	1732	-0.898520	1803	7.590493
1520	-0.585466	1591	3.990260	1662	4.160610	1733	-1.022912	1804	11.698636
1521	-0.338934	1592	3.636858	1663	2.414765	1734	-1.025295	1805	16.759206
1522	-0.031256	1593	3.174849	1664	1.161116	1735	-0.908232	1806	22.742162
1523	0.327487	1594	2.668748	1665	0.322342	1736	-0.705843	1807	29.582735
1524	0.717984	1595	2.168361	1666	-0.197481	1737	-0.435257	1808	36.934682
1525	1.108106	1596	1.713005	1667	-0.373757	1738	-0.107467	1809	44.059624
1526	1.449000	1597	1.335736	1668	-0.170551	1739	0.253697	1810	49.975244
1527	1.671188	1598	1.067180	1669	0.565543	1740	0.627319	1811	53.808502
1528	1.736255	1599	0.938634	1670	1.554053	1741	0.935529	1812	54.788309
1529	1.634626	1600	0.984118	1671	2.655387	1742	1.139796	1813	52.061049
1530	1.384916	1601	1.136002	1672	3.678640	1743	1.273884	1814	45.093169
1531	1.034945	1602	1.205290	1673	4.596831	1744	1.328221	1815	35.942857
1532	0.664238	1603	1.233335	1674	5.188302	1745	1.254022	1816	26.025719
1533	0.387521	1604	1.441087	1675	5.104891	1746	1.044854	1817	16.441492
1534	0.343654	1605	1.968859	1676	4.749226	1747	0.750255	1818	8.029658
1535	0.622415	1606	2.595485	1677	4.397785	1748	0.496449	1819	1.361456
1536	1.264941	1607	3.279447	1678	4.264109	1749	0.364806	1820	-3.447169
1537	2.260935	1608	3.723247	1679	4.528328	1750	0.388548	1821	-6.557303
1538	3.542246	1609	3.626133	1680	5.219056	1751	0.580163	1822	-8.194897
1539	4.972905	1610	3.255417	1681	6.217014	1752	0.952330	1823	-8.682095
1540	6.336316	1611	2.800082	1682	7.098892	1753	1.425749	1824	-8.399440
1541	7.417389	1612	2.395272	1683	7.841327	1754	1.945504	1825	-7.569228
1542	8.080735	1613	2.093197	1684	8.157707	1755	2.376162	1826	-6.472618
1543	8.259849	1614	2.063282	1685	7.702862	1756	2.712374	1827	-5.292854
1544	7.950485	1615	2.344697	1686	7.275785	1757	2.925689	1828	-4.181060
1545	7.208855	1616	2.727729	1687	7.083945	1758	2.992591	1829	-3.179256
1546	6.154733	1617	3.211670	1688	7.144502	1759	2.999633	1830	-2.362116
1547	4.978862	1618	3.737673	1689	7.304244	1760	3.072628	1831	-1.738041
1548	3.858701	1619	4.399903	1690	7.512446	1761	3.185574	1832	-1.280698
1549	2.909808	1620	5.271096	1691	7.710298	1762	3.263911	1833	-0.902418
1550	2.197049	1621	6.289023	1692	7.901689	1763	3.212077	1834	-0.544832
1551	1.744083	1622	7.087656	1693	7.938753	1764	2.967869	1835	-0.217467
1552	1.540489	1623	7.361019	1694	7.660115	1765	2.614371	1836	0.027978
1553	1.546299	1624	7.103181	1695	7.344904	1766	2.194049	1837	0.179477
1554	1.694029	1625	6.514305	1696	6.771099	1767	1.798704	1838	0.272920
1555	1.754830	1626	5.992669	1697	5.748303	1768	1.430403	1839	0.319411
1556	1.546903	1627	5.531187	1698	4.337483	1769	1.090480	1840	0.339092
1557	1.255971	1628	4.967583	1699	2.853647	1770	0.817722	1841	0.372164
1558	1.043319	1629	3.976838	1700	1.653592	1771	0.607539	1842	0.444075
1559	1.048701	1630	2.559513	1701	1.134552	1772	0.461478	1843	0.553564
1560	1.392466	1631	1.143207	1702	1.234701	1773	0.414549	1844	0.730222
1561	1.973052	1632	0.093002	1703	1.828424	1774	0.543985	1845	0.929921
1562	2.569080	1633	-0.493344	1704	2.690397	1775	0.893890	1846	1.076843
1563	3.011838	1634	-0.747319	1705	3.484281	1776	1.393380	1847	1.123370
1564	3.323042	1635	-0.766054	1706	4.176491	1777	1.987133	1848	1.143646
1565	3.526205	1636	-0.602151	1707	4.688338	1778	2.557209	1849	1.264411
1566	3.549691	1637	-0.494360	1708	4.963561	1779	3.069727	1850	1.490967
1567	3.352606	1638	-0.388087	1709	4.708361	1780	3.410014	1851	1.771030
1568	3.136115	1639	-0.214767	1710	3.788753	1781	3.584108	1852	2.025641
1569	2.892777	1640	-0.004724	1711	2.859734	1782	3.554171	1853	2.181940
1570	2.583789	1641	0.191199	1712	2.116727	1783	3.291458	1854	2.146811
1571	2.195515	1642	0.399748	1713	1.487687	1784	2.933046	1855	1.909970
1572	1.738689	1643	0.679631	1714	0.967430	1785	2.549917	1856	1.544927
1573	1.225624	1644	1.036373	1715	0.466407	1786	2.184798	1857	1.125141

Source: Abildgren (2010)