The Fehmarn Belt Duopoly – Can the Ferry Compete with a Tunnel?[☆]

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Abstract

The Fehmarn Belt is a strait between Denmark and Germany, currently served by a ferry operator. We analyse competition between the ferry service and a planned tunnel, the Fehmarn Belt Fixed Link. We develop a differentiated duopoly model to address two questions: 1. Will the tunnel induce the ferry to exit the market once it operates? 2. Will the tunnel's toll revenue suffice to cover its cost? Using real-world data and traffic forecasts, we show that it should not be taken for granted that the ferry will exit the market, and that if the ferry competes, the tunnel project will make a loss.

Keywords: Fehmarn Belt Fixed Link, transportation economics, competition analysis, route choice, duopoly, product differentiation
JEL classification: R42, D43, L91

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1. Introduction

The Fehmarn Belt is a strait between the German island of Fehmarn and the Danish island of Lolland. Scandlines, a privately owned ferry operator, connects the two islands with 90-110 crossings per day. Denmark plans to build a fixed link in the form of a tunnel which could reduce travelling time by about one hour. It has set up a state-owned company, Femern A/S, as the operator of the Fehmarn Belt Fixed Link, which benefits from publicly guaranteed loans and expects to receive European grants covering about 10 percent of building cost. Apart from this, Femern A/S is supposed to operate independently of public resources and receive all its revenues from user fees. In fact, the EU Market Economy Investor Principle requires the Fehmarn Belt Fixed Link to operate as a profitable business, such that a hypothetical private investor would be willing to fund the project.

In order to show that the project is indeed economically viable, the tunnel operator has commissioned a series of studies and forecasts. Overall, the studies suggest that the tunnel will manage to be a profitable business and will also be beneficial from a socio-economic perspective (Intraplan and BVU, 2014; Incentive, 2015; Femern A/S, 2016). But the predicted margin of success is small. These studies presume that the tunnel tolls will be similar to historical ferry list prices and predict that the ferry will exit the market once the tunnel has been built. DIW Econ (2015b,a,c) questions these assumptions, noting in particular that appropriate ferry reactions are not sufficiently accounted for.

But for any assessment of the tunnel's economic viability it is crucial to anticipate the competitive equilibrium of the ferry-tunnel duopoly. We thus propose a simple model of ferry-tunnel competition. The model is focused on two questions:

1. Will the tunnel induce the ferry to exit the market once it operates?
2. Will the toll revenues cover all costs of constructing and operating the tunnel?

We also analyse these questions empirically. To do so, we calibrate the model with real-world data and determine the profitability of ferry and tunnel. Our results depend on an assumption about the elasticity of demand. With low elasticity, the ferry will stay in the market and the tunnel project will make a loss. With higher elasticity, the ferry will exit and the tunnel will be profitable. Judging from the respective equilibrium demand volumes, the former scenario is more likely.

Our findings contribute to the ongoing debate about the rationale for building the Fehmarn Belt Fixed Link. We show that it should not be taken for granted that the ferry will exit the market. This has substantial impact on the question whether the tunnel project can be sustained as a profitable business. Further, it affects the question whether the project creates net benefits for society as a whole. What is more, our model can serve as a blueprint for applied analyses of other cases of competing types of transportation. Though more elaborate models of route choice exist, the simplicity of our approach allows for integration into a game-theoretic setup. Using the concept of Nash Equilibrium, one can properly analyse the strategic interaction and price setting of competing services.

The following section relates our analysis to existing literature. In sections 3 and 4, we develop the theoretical model and characterize the equilibrium. In sections 5 we describe the empirical analysis. We present the result in section 6. In section 7, we discuss our findings. In section 8, we conclude. Technical details of both the theoretical and empirical analysis are relegated to the Appendix.

2. Related Literature

Literature on the Fehmarn Belt project. Several recent studies assess the economic viability of the Fehmarn Belt Fixed Link tunnel project. In its most recent financial analysis, the tunnel operator Femern A/S (2016) calculates that the project will have an amortisation of 36 years. This would make the project a profitable business. A cost-benefit analysis commissioned by the Danish Ministry of Transport concludes that the tunnel will also be beneficial for society as a whole (Incentive, 2015). These reports, plus two external quality assessments (Ernst & Young, 2016; Cowi, 2015), provide the latest economic support for the Fixed Link.

The studies put forward in support of the tunnel are based on the traffic forecast of Intraplan and BVU (2014). The forecast presumes that the Fixed Link will charge a price of 65 Euro per car and 267 Euro per lorry. These prices are based upon historical ferry list prices. In their main scenario, Intraplan and BVU (2014) assume that the ferry will exit the market once the tunnel operates, securing the Fixed Link a 100 percent market share. In a sensitivity scenario, Intraplan and BVU (2014) predict the Fehmarn Belt traffic under the assumption of continued ferry operation, but note that ferry operations are unlikely to be profitable.

In a related study prepared for the ferry operator Scandlines ApS, DIW Econ (2015c,b) challenges the assumption that the ferry will exit the market and concludes that the ferry could very well continue to operate. Accountanting firms have also analysed the financial prospect of ferry operation, focusing explicitly on Scandlines. KPMG (2016) finds that continued ferry operation would be unlikely. Deloitte (2016), on the other hand, considers it more likely that Scandlines will remain profitable.

The paper at hand is based on the analyses of DIW Econ (2015c). In section 7, we detail the differences between our findings and the reports of Intraplan and BVU (2014) and Femern A/S (2016).

Literature on infrastructure projects. There exists a host of ex-ante and ex-post studies analysing the impact of large-scale infrastructure projects like the Fehmarn Belt tunnel. Several meta-studies provide an overview and a general assessment (e.g. Engel et al., 2004; Flyvbjerg, 2009, 2014). These studies indicate that the benefits of infrastructure projects are often overestimated, mostly due to forecasts overestimating the level of transport volumes (demand). Flyvbjerg et al. (2005) reassess more than 200 demand forecasts for transportation infrastructure projects. Roughly half of the ex-ante demand analyses overestimated passenger traffic demand, on average by 106 percent. Hence, most projects were not as financially sound as initially anticipated. This in turn can lead to benefit shortfalls when compared with regional or economic upfront expectations. The meta-studies stress the need to be careful when forecasting demand. The paper at hand does not challenge the basic estimates on traffic flows on the Fehmarn Belt, but questions the market share that the tunnel will be able to serve.[1]

The Channel Tunnel at the Strait of Dover is one of the most well-studied large-scale infrastructure projects. The tunnel is much longer than the planned Fehmarn Belt tunnel and does not feature roads but only rails. Still its setting is similar to the Fehmarn Belt Fixed Link, as the Channel Tunnel competes with ferry operators serving a similar route. The development of competition can thus provide insights for the Fehmarn Belt.

In his comprehensive ex-post analysis Anguera (2006) reports that ex-ante studies on the Channel Tunnel predicted the market share for passengers to be in the range of 30 to 45 percent. From 1998 onwards, the tunnel fulfilled

[1] For a critical assessment of the total traffic flows forecast for the Fehmarn Belt, see DIW Econ (2015c, Chapter 4).

these projections; in 2003 its market share was 43 percent. But in order to achieve these market shares, the operator Eurotunnel had to decrease prices significantly:

> Soon after the opening of services, Eurotunnel found itself in a price war with the ferry operators and prices quickly fell by an average 35 to 45 percent. It became clear that Eurotunnel would not be able to achieve the levels of traffic, and especially the predicted levels of revenue. [...] Eurotunnel grossly underestimated its competitors and their potential to significantly cut their prices and still remain in business. (Anguera, 2006, p. 304)

Kay et al. (1989, 1990) predicted such an outcome in their ex-ante studies. They extensively discussed competition between the Channel Tunnel and the ferries, and found that the tunnel should aggressively undercut ferry prices to gain market shares. More specifically, they argued that the tunnel's high capacity and very low marginal cost would drive down prices and reduce private profitability of the tunnel project. Their predictions – as of now confirmed – are quite similar to the findings of the paper at hand: The tunnel will have a hard time maintaining a high price level if ferries serve the same route.

The Channel Tunnel not only suffered from low prices but also from low overall demand. Chevroulet et al. (2007, p. 23) report that "the market size had been overestimated by a factor 1,5 to 2." After opening, the operator of the Channel Tunnel was able to cover its operational costs, but could not repay its huge debt burden and has since been subject to various debt restructuring measures to avoid bankruptcy (Winch, 2013).

Further ex-post analyses of additional socio-economic and regional impacts of the competition on the Dover straits, for instance in terms of employment, have been conducted by Hay et al. (2004) and Thomas and O'Donoghue (2013). The Eurotunnel also serves as a case study for the analysis of more specific issues, such as the influence of peak-load pricing on demand and infrastructure investments (Glaister, 1976; Mills and Coleman, 1982).

The Øresund Bridge, connecting Denmark and Sweden, is another prominent example of a fixed link that competes with a ferry service. But the ferry serves a different route, not directly connecting Copenhagen and Malmö, and thus competes less viciously. There are also no flights covering the same route. Knudsen and Rich (2013) identify this lack of fierce competition from other means of transport as a main factor of the bridge's success. In contrast to many other projects, demand and revenue for the Øresund Bridge were not overestimated (Knudsen and Rich, 2013). For further analyses on the Øresund Bridge, see Madsen et al. (1999).

Literature on industrial organization. Our model relates to classic theories of industrial organization, notably duopoly and oligopoly theory. Hotelling (1929) provides one of the early contributions. Today, two of the most prominent workhorse models are Bertrand and Cournot competition. In the classic versions, firms are symmetric, have identical cost structures, and offer homogeneous goods. On the Fehmarn Belt, the products of tunnel and ferry will be heterogeneous, as will be the cost structures of the competitors. There is a large literature on product differentiation (e.g., Shaked and Sutton, 1987, 1982; Singh and Vives, 1984; Bester, 1992; Motta, 1993). One of the canonical insights is the observation that product differentiation can relax competition and support equilibrium prices that exceed marginal cost, even if firms compete on prices and capacity is not restricted. This is also the case in our model.

The industrial organization literature also examines the entry and exit decisions of firms, as well as price wars (e.g., Bresnahan and Reiss, 1991, 1990; Slade, 1989; Lutz, 1997; Allen et al., 2000). The question of whether the ferry will compete with the tunnel or exit the market is central in both our theoretic and empirical analysis. The contestable market paradigm suggests that the mere possibility of entry can force an incumbent to behave as if there was actual competition (Baumol et al., 1982). In the case of the Fehmarn Belt tunnel, we do not expect the threat of ferry entry to be sufficient to create competitive pressure. Once built, the tunnel can react very quickly to changing competitive environments, because its single most important lever is its price. If the tunnel is not committed to a particular pricing scheme, there is no need to preadjust the tunnel strategy to potential competition. As long as the ferry abstains from the market, the tunnel can behave as a monopolist.

Other branches of the oligopoly literature highlight the role of capacity, either as a given constraint or as a strategic choice (e.g. Benoit and Krishna, 1987; Allen et al., 2000; Boccard and Wauthy, 2010). In our model, ferry capacity is endogenous, but we do not focus on capacity as a strategic choice.

In terms of empirical analyses of duopolies, aviation is a well-studied industry. On many routes only few carriers compete for customers, making it a prime industry for studying competition in highly concentrated markets.[2] We also study one particular route with two competitors. Their services are more heterogeneous than the offerings of competing airlines, though.

3. Model

We analyse a repeated game starting after the opening of the tunnel. Figure 1 depicts the game in a stylized, extensive form. In each period, the ferry decides whether or not to compete with the tunnel. If it does not compete, the tunnel enjoys a monopoly and the ferry does not take any further actions in the period. If the ferry competes, it fixes a schedule in order to set the frequency of service. Afterwards, tunnel and ferry simultaneously set prices in order to attract customers. In the next period, the ferry decides again whether to compete and can set a new schedule.

We assume that both players are rational and maximise profits. This is a fairly reasonable assumption for the privately owned ferry; it is less clear whether the publicly owned tunnel intends to do so. In fact, according to the website of Femern A/S "the company is not intended to make profits for the owner."[3] Nonetheless, profit optimizing ensures that the tunnel exerts maximal effort to prevent any losses as required by the EU Market Economy Investor Principle.

The tunnel has a simple cost structure: The cost of building the tunnel is a sunk investment. As our analysis starts after the tunnel opening, we consider the cost of operating and maintaining the tunnel as fixed, i.e. we assume that shutting down the tunnel is never an option. Cost estimates for building, operation and maintenance are available from the operator Femern A/S (2016). According to Williams et al. (2010) there will be hardly any congestion in the tunnel, so we expect that the tunnel's capacity constraint is typically not binding. Thus, we can further assume that the marginal costs of the tunnel are zero, so that additional vehicles do not increase costs. The cost structure implies that in each stage game the tunnel behaves as if it had no cost at all. The cost structure of the ferry is more involved and is described later.

The payoff in any given period depends on the current period's actions only, not on the outcomes of previous periods. We thus proceed with describing and

[2] See, e.g., Hurdle et al. (1989); Borenstein (1989); Berry (1992); Brander and Zhang (1990, 1993). For a different industry, see Parker and Röller (1997) who study collusive duopoly conduct in the mobile telephone industry.

[3] http://femern.com/en/Tunnel/Finance/Ticket-prices-in-the-Fehmarnbelt-tunnel.

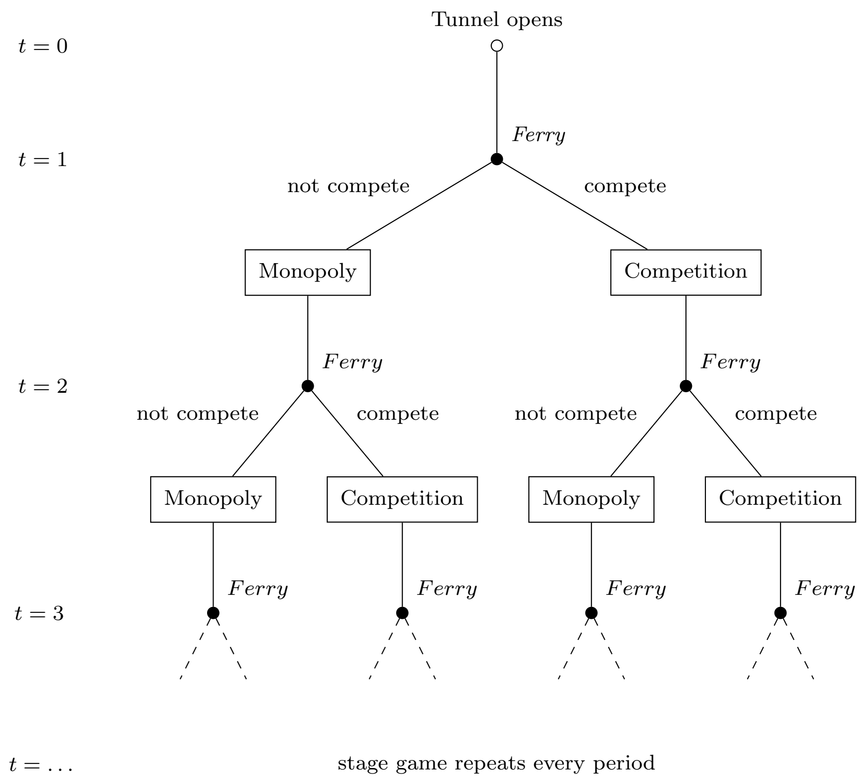

Figure 1: The game tree

analysing a generic period. In the appendix, we present a formal discussion of the repeated game. At the end of section 4, we discuss predatory pricing strategies designed to force the ferry out of the market after some initial periods of price war.

If the ferry decides against competing, the tunnel sets a price P_T, facing demand $D(P_T)$; the ferry does not take further action, and has neither costs nor revenues in this period. If the ferry decides to compete, tunnel and ferry engage in a *competition subgame* and proceed as follows.

3.1. The competition subgame

A competition subgame begins if the ferry chooses to compete in a given period. It consists of two phases: First the ferry sets the frequency of service, then both ferry and tunnel set a price to compete for customers. In the following sections, we describe demand conditions, then, using backward induction, we detail on the price setting and finally consider the frequency choice.

Demand, prices and market shares. To determine the total demand and the market shares, let P_T be the tunnel price and P_F be the ferry price. We assume that the total demand $D(P_T)$ for crossings depends on the tunnel price only, not the ferry price. Hence, by setting its price P_F, the ferry influences only its market share but not the market size. In contrast, the tunnel's price P_T influences both market shares and total demand. The reason behind this restrictive assumption is the availability of data, as most traffic forecasts only include tunnel traffic.[4]

Tunnel and ferry offer similar but not identical products. Both enable customers to cross the Fehmarn Belt, but the means of transportation are obviously quite different. Thus, the price is not the only difference between the two products. In particular, taking the ferry takes longer than using the tunnel. Let w be the difference in crossing times, including all time-relevant differences like journey/sailing duration and check-in/out times. It also accounts for the fact that ferry passengers have to wait for the next available ferry (see table B.6 in the appendix). For now, consider w as fixed.[5] The time saved when taking the tunnel rather than the ferry translates into a *monetary advantage* that the tunnel has over the ferry. Customers are heterogeneous in this respect: Some customers enjoy the ferry ride or experience fear driving through the tunnel; others dislike sailing. Some lorry drives might prefer the ferry as it allows them to take their statutory rest break during the passage. Generally, peoples' value of time differ. All these aspects imply that different customers have a different valuation of the general characteristics and the time-saving associated with taking the tunnel.[6] Let θ_i be the type of customer i such that the monetary advantage of the tunnel as perceived by customer i amounts to $\theta_i w$. Then he or she takes the ferry rather than the tunnel if

$$P_F + \theta_i w < P_T \; . \tag{1}$$

[4]Note also that this assumption reduces the reliance on estimates for certain (cross)-price elasticities. Estimating additional ferry demand is difficult. By means of this assumption we ensure that our results are not driven by overly optimistic assumptions on additional ferry demand. Hence, if the model predicts that the ferry is able to compete, it will be a robust prediction, as our model tends to underestimate ferry demand.

[5]We later relax this assumption to account for the fact that the ferry can actually influence the waiting time by changing the frequency of ferry operations.

[6]We abstract from the question of transport of hazardous goods. In general it can be asumed that all hazardous goods can be transported through the tunnel, though some restrictions might apply (Williams et al., 2010).

For some customers, taking the ferry might take prohibitively long; their value of time is so high that they would never take the ferry (for any reasonable price difference). Let $(1-\delta)$ be the share of these customers,[7] so the ferry actually only competes for the remaining share of customers, δ. They choose between ferry and tunnel based on prices and individual value of time. We assume that among those customers, the share of customers with time value θ_i is uniformly distributed between 0 and $\bar{\theta}$. That is, no customer has a negative value of time and no customer has a value higher than $\bar{\theta}$.

The share of customers taking the ferry given prices P_F and P_T is[8]

$$\delta Pr[P_F + \theta_i w < P_T] = \delta Pr[\theta_i < (P_T - P_F)/w] = \delta \frac{P_T - P_F}{\bar{\theta} w} \ . \tag{2}$$

To sum up, for given prices P_T and P_F, the ferry faces a demand of

$$D_F = \delta \frac{P_T - P_F}{\bar{\theta} w} D(P_T) \ , \tag{3}$$

and the tunnel faces a demand of

$$D_T = \left(1 - \delta \frac{P_T - P_F}{\bar{\theta} w}\right) D(P_T) \ . \tag{4}$$

Frequency choice and ferry cost structure. Now consider the frequency choice. Frequency refers to the frequency of the ferry service: how many ships depart per hour? The frequency depends on both the number of ships in operation and their schedule. Currently, a typical schedule has four active ships making continuous round-trips. This results in a frequency of two ferry departures per hour; in other word, at each port, a ship leaves every 30 minutes. So for the sake of concreteness, think of the frequency as a number representing the amount of regular ferry departures per hour.[9] For the model, the frequency is relevant in two respects. It determines (a) the cost of ferry operations and (b) the average waiting time for the next available ship.

(a) The cost of ferry operation consists of two elements: semi-fixed costs C_F

[7] Customers who would always prefer the faster tunnel include, for example, business travellers by car with tight time restrictions and lorries transporting perishable goods.

[8] To simplify notation, equation (2) presumes that $(P_T - P_F)/w \leq \bar{\theta}$. Throughout the exposition of the model, we assume that this condition is met. In the application (section 5), we explicitly account for it.

[9] In the application (section 5), the schedule is more intricate, e.g. varying by season and by time of day. There, frequency f is not a one-dimensional object.

and marginal costs c_F. The semi-fixed costs are fixed in the sense that they do not change with additional passengers. But they are fixed only for a single period. If the ferry does not compete in a particular period, it will not incur any cost. What is more, the semi-fixed costs are variable in the sense that they change with the selected schedule and frequency. In particular, they increase with the number of ships in operation, the number of trips per ship, and the schedule.[10] Hence, the ferry can influence the level of semi-fixed cost once per period. If the ferry competes, semi-fixed costs are a function of frequency f, i.e., $C_F = C_F(f)$. Generally, the higher the frequency f, the higher are the semi-fixed costs $C_F(f)$. Marginal costs c_F are assumed to be constant and refer to incremental costs induced by additional (marginal) passengers, namely additional cars or lorries.[11]

(b) The frequency determines the average waiting time for the next available ship and influences the difference in crossing times between tunnel and ferry, w. The time advantage of the tunnel is thus a function of f, i.e., $w = w(f)$. Generally, the higher the frequency, the more ships depart per hour and the lower is the average waiting time, resulting in a lower time difference w.

Let f be a frequency choice and $C_F(f)$ be the semi-fixed cost associated with this frequency. Then, the profits of the ferry are

$$\pi_F = (P_F - c_F)\delta \frac{P_T - P_F}{\bar{\theta} w(f)} D(P_T) - C_F(f)\,. \tag{5}$$

When the ferry sets a frequency, it anticipates the resulting equilibrium prices (see next section) and chooses the frequency that maximises profits π_F.

4. Equilibrium

Ferry and tunnel play the same stage game every period. We begin our analysis by characterizing the subgame perfect Nash equilibrium of the stage game. The requirement of subgame perfection is relevant because each stage game has an extensive structure. Price setting happens only after the ferry has

[10] For instance, there is a considerable cost difference between a ship that only sails during the day and one that is en route 24 hours.

[11] In reality, of course, there is a relation between passenger volume, frequency and schedule: when volume hits capacity limits, the frequency has to be increased in order to meet demand. Currently, however, only a very small percentage of ferry crossing are fully utilised. Hence, for the sake of tractability of the model, it is fair to assume that capacity never is an issue. Yet, in the empirical analysis, we explicitly check for capacity constraints.

decided to compete or not. The tunnel might want to claim that it will set an aggressively low price when the ferry competes. If the ferry believes this threat and refrains from competition, the tunnel's claim is never tested and the tunnel can enjoy monopoly profits. However, such a threat is not credible in the stage game if an aggressively low price is not optimal in the subgame that starts after the ferry has chosen to compete. To rule out non-credible threats, we require a stage game equilibrium to be subgame perfect. Formally such a subgame perfect *stage game equilibrium* consists of

- *a ferry action* $a \in \{c, nc\}$ *determining whether or not the ferry competes* ($c =$ *compete*, $nc =$ *not compete*),
- *a ferry price* P_F *and a frequency* f, *and*
- *a tunnel price* $P_T(a)$ *conditional on ferry action* a,

such that:

- $(P_F, P_T(c), f)$ *is a subgame perfect equilibrium of the subgame beginning with the ferry choosing to compete.*
- $P_T(nc)$ *maximises the tunnel's monopoly revenue* $D(P_T)P_T$.
- *The ferry's decision whether to compete is a best response, i.e.,* $a = nc$ *if ferry profits in* $(P_F, P_T(c), f)$ *are negative, and* $a = c$ *otherwise.*

We use backward induction to find the equilibrium, beginning with price setting and frequency choice.

Equilibrium prices in the competition subgame. Fix some ferry frequency f. To support an equilibrium, a pair of prices (P_F, P_T) must be such that P_F maximises the ferry's net revenue R_F, and P_T maximises tunnel revenues R_T, with

$$R_F = (P_F - c_F)\delta\frac{P_T - P_F}{\bar{\theta}w(f)}D(P_T) \tag{6}$$

and

$$R_T = \left[1 - \delta\frac{P_T - P_F}{\bar{\theta}w(f)}\right] D(P_T)P_T \ . \tag{7}$$

Solving for such a pair of prices is a straightforward exercise, but requires some algebra. The ferry's best response is

$$P_F^* = \frac{P_T + c_F}{2} \ . \tag{8}$$

Put differently, the ferry chooses as its price the average of its marginal cost and the tunnel price. Notice that the ferry's best response does not depend on the frequency f.

For notational convenience, define $\bar{v} := \bar{\theta} w(f)$. Then the tunnel's best response is

$$P_T^* = \frac{\bar{v}/\delta + P_F}{2 - \epsilon}(1 - \epsilon) \; , \tag{9}$$

where $\epsilon = -P_T D'(P_T)/D(P_T)$ is the absolute elasticity of demand D with respect to the tunnel's price P_T.

It now follows that the equilibrium prices in the competition subgame are

$$P_T^{EQ}(c) = \frac{(1 - \epsilon)(c_F + 2\bar{v}/\delta)}{3 - \epsilon} \; , \tag{10}$$

$$P_F^{EQ} = \frac{(2 - \epsilon)c_F + (1 - \epsilon)\bar{v}/\delta}{3 - \epsilon} \; . \tag{11}$$

The equilibrium prices are quite intuitive. They both increase when the ferry's marginal costs c_F increase. They also increase when the tunnel's monetary advantage for customers, measured by $\bar{v}$, increases. When $\bar{v}$ is low, the tunnel has a small advantage over the ferry, and minor price cuts will attract many customers. Hence, price competition is intense and equilibrium prices are low. When $\bar{v}$ is high, the tunnel has a large advantage over the ferry and price cuts have less impact. Thus, competition is less fierce and equilibrium prices are higher.

Equilibrium prices are lower when δ is higher. The parameter quantifies the share of the market over which ferry and tunnel actually compete. If δ is high, the tunnel needs to fight for a large market share and sets low prices. If δ is low, the tunnel can capture a high market share without competition from the ferry and high prices are more attractive. Finally, the equilibrium prices are lower if ϵ is higher. When the (absolute) elasticity ϵ is high, lowering prices attracts many additional customers and is thus more attractive than when ϵ is low.

Equilibrium frequency. When the ferry chooses its frequency f, it anticipates the equilibrium prices $P_T^{EQ}(c)$ and P_F^{EQ}, which are influenced by f. The ferry faces various trade offs: A higher frequency implies better service, making the ferry more attractive for customers. But it also increases cost. What is more, the higher the frequency, the more alike are the offerings of ferry and tunnel and the more intense is the competition.

Further equilibrium choices. The ferry's optimal decision on whether to compete or not depends on whether the equilibrium values for $(P_F, P_T(c), f)$ yield a positive ferry profit or not. It chooses to compete if and only if it anticipates positive profits in the competition subgame. If the ferry does not compete, the tunnel can set a monopoly price and is restricted only by the demand side.

Equilibrium outcome. We show in the Appendix that when "compete" is the equilibrium action of the stage game, there is a subgame perfect equilibrium of the repeated game in which the ferry competes in every period. If "not compete" is the equilibrium action in the subgame, there is a subgame perfect equilibrium of the repeated game in which the tunnel enjoys a monopoly in every period. So when the stage game equilibrium results in a monopoly, the ferry receives a payoff of zero in every period; it has neither revenues nor costs. The tunnel can reap monopoly revenues. When the stage game equilibrium results in competition, the ferry obtains positive profits in every period. The tunnel still generates revenues, but those fall short of the monopoly revenues.

The tunnel revenues depend on the equilibrium outcome. But the tunnel's cost do not. By assumption, all tunnel costs are sunk or fixed and amount to (a discounted value of) C_T. The total revenues that the tunnel accrues in the repeated game equal the discounted sum of the revenues in the stage games. We say that the tunnel is *ex-ante profitable* if those accumulated revenues exceed C_T.

A note on predatory pricing strategies. Our analysis focuses on repeated static equilibria. Strategies supporting a subgame perfect equilibrium of the stage game also support a subgame perfect equilibrium of the repeated game, irrespectively of time horizon or discount factors. This makes for robust predictions. Still, the tunnel might try to use some form of predatory pricing: offer low prices in the beginning until the ferry operator gives up and exits. Afterwards, the tunnel could increase prices and reap monopoly profits. Whether or not such a strategy is successful depends on additional parameters such as the financial funds available to both competitors and the internal discount rates.

One intuition behind a predatory pricing strategy is that over time the cost structure of the ferry changes. For example, the ferry operator might be able to compete with low prices as long as no costly investments are necessary. Once the legacy ships need replacement, though, the ferry might not be able to fund new investments and is forced to leave the market. Such considerations are valid but path-dependent. Our model does not rely on such path dependence. Instead, the ferry cost model assumes on-going operation with no reliance on legacy capital. So if "compete" is the optimal ferry action in a certain period, it typically is optimal in any other period as well. Therefore, our analysis might underestimate the ferry's capabilities to compete in the short-term.

Another intuition behind a predatory pricing strategy is that the ferry is able to take losses for some time, but will eventually need to exit the market if losses accumulate. Therefore, the tunnel could simply set (unsustainable) low prices in the beginning and wait for the ferry to leave. Yet, such a scenario requires a certain lack of foresight. If the ferry is rational and anticipates the tunnel's strategy, it will exit the market right away rather than incur losses in the first place (assuming the tunnel strategy is credible, i.e. subgame perfect). This is exactly what happens in case C of the empirical analysis (see sections 5 and 6).

Besides economic considerations, there is also a legal concern. If the tunnel sets low prices with the clear intention of making the ferry exit and raising prices afterwards, it essentially uses its state-aided deep pockets to eliminate competitors. Such behaviour would almost certainly raise objections from competition authorities. Whether authorities can actually ban such a strategy on legal grounds is a different matter. The tunnel has very low marginal costs and proving that prices above marginal cost are predatory is typically difficult.

5. Empirical Analysis

To address our research questions empirically, we calibrate the model using real-world data, forecasts and estimates. This section describes the central elements of the calibration. More details and parameter values are relegated to the appendix. Each period of the theoretical model is assumed to be equal to one year. With respect to the ferry, we focus on the yearly profits, i.e. the payoff from each stage game. To access the tunnel's profitability, we consider the first 50 years of operation. We use this particular time horizon because the tunnel operator Femern A/S (2016) considers 50 years to be the maximum repayment time, and because Incentive (2015) uses a time span of 50 years for their cost-benefit analysis. We examine whether the revenues from this 50-year period suffice to cover all costs.

Demand. In 2014, $1,542,000$ cars and $425,000$ lorries crossed the Fehmarn Belt (KPMG, 2016, p. 59). Forecasts presume steady traffic growth until 2025, a steep traffic jump once the tunnel opens in 2026, and continued growth afterwards, resulting in $5,135,000$ cars and $855,000$ lorries in 2051 (see table B.8 in the appendix). The forecast assumes tunnel toll levels based on the ferry operator's historic list prices, amounting to 65 Euro per car and 267 Euro per lorry. We refer to these values as *reference prices*, denoted P_{T0}.

To simplify the analysis, we take the average yearly traffic after opening and use this as the annual *reference demand* for all periods, denoted D_0. To be able to analyse the effects of price changes, we need to use a certain demand function. To keep it simple, we assume that the demand function $D(P_T)$ is represented by

$$D(P_T) = \alpha P_T^{-\epsilon} \ . \tag{12}$$

That is, the absolute price elasticity of demand with respect to tunnel price P_T is constant and equal to $\epsilon > 0$. Parameter α is a scaling factor that we calibrate using the reference values for prices and demand, i.e., $\alpha := D_0/P_{T0}^{-\epsilon}$.

We lack information or forecasts on the value of demand elasticity ϵ. Thus, we analyse three different cases:

- Case A assumes a zero elasticity: $\epsilon = 0$ (benchmark case).
- Case B assumes a low elasticity: $\epsilon = 0.1$.
- Case C assumes a higher elasticity: $\epsilon = 0.6$.

We also considered higher elasticity values but found that they would lead to unrealistically high demand volumes when prices take the equilibrium values.[12] Also, it is reasonable to assume that elasticity is rather low because the alternatives to crossing the Fehmarn Belt typically involve considerable detours.

Net present value of the tunnel project. Construction, financed by debt, is the tunnel's main cost factor. Thus, repayment of debt and the associated interest payments are the main yearly costs. We assume a 50 year repayment period after opening. To study the ex-ante profitability of the tunnel, we calculate the present value of the tunnel's expected cash flow over this period. Each year, the tunnel receives revenues from passengers (cars and lorries) according to the predictions of our equilibrium model. It has to pay for operation and maintenance and receives additional revenues from buses and trains. We take

[12] For instance, an elasticity of 0.9 yields 5 times the original demand.

the values for the latter items as given, referring to the operator's financial analysis (see table B.4 in the appendix). From the discounted sum of yearly net cash flows we subtract the construction cost and add EU subsidies expected to be 10 percent of upfront cost. The result is the net present value of the tunnel project. The tunnel is *ex-ante profitable* if the net present value is positive.

Due to a lack of detailed data, we implicitly make the favorable assumption that the tunnel operator has to pay for building the tunnel just before opening the tunnel. Thus, we assume that no interest payment is necessary during the building period. Consequently, our results tend to overestimate the profitability of the tunnel and underestimate the repayment period.

Ferry schedule and cost structure. The cost of the ferry operation depends on the ferry schedule (corresponding to a frequency f), as well as on the number of passengers. To estimate the ferry cost, we reached out to Scandlines ApS, the company that currently operates the Fehmarn Belt ferry service and commissioned DIW Econ to study the economic viability of the Fehmarn Belt Fixed Link (DIW Econ, 2015a,b,c). Scandlines provided confidential business figures as well as general price data relating to the ferry business. Based on this data, DIW Econ (2015c) develops a model to estimate semi-fixed cost $C_F(f)$. It includes fixed costs for port infrastructure and variable costs depending on the total number of ships in operation and the total number of trips. The main drivers of variable cost are the financing of ships, staff and bunker costs.

More frequent departures provide more capacity and are more attractive for customers due to lower waiting times but have higher cost. In addition, there is a more subtle effect: With more frequent departures the services of ferry and tunnel become more alike as the difference in crossing time shrinks. This results in more fierce competition. To understand the implications, consider the hypothetical option to increase the speed and the frequency such that it matches the crossing time of the tunnel. Would the ferry choose this option? Probably not. If the two competing services were nearly homogeneous, price competition would result in equilibrium prices close to marginal cost and neither the tunnel nor the ferry could cover their fixed cost.

We use the cost model of DIW Econ (2015c) to determine the optimal ferry schedule. Our findings are as follows.

- In cases A and B, the ferry chooses the following schedule: During daytime, two ships are in operation, resulting in one ferry departure per hour (and direction). At night, one ship is in operation, resulting in one ferry departure every two hours.

- In case C, the ferry operates with one ship all day and night, resulting in one ferry departure every two hours.

In cases A and B the ferry could improve its profits by using the same schedule than in case C. But this schedule would not be feasible in cases A and B, because a single ship could not satisfy the equilibrium demand. In case C, the equilibrium ferry market share is lower and one ships suffices.

We cannot claim that these schedules are strictly optimal, as we did not run a fully fledged numerical optimization over all possibilities. But in the context of our model the schedule performs very well for the ferry. Still, Scandlines plans to employ a much more frequent service after the tunnel opening.[13] Their internal assumptions likely differ from the settings of our model. Nevertheless, their plans indicate further optimization potential.

In addition to the semi-fixed cost, each additional passenger induces marginal costs. Due to a lack of data, we roughly estimate these and assume that an additional car costs 5 Euro and an additional lorry costs 15 Euro. Scandlines confirmed the marginal cost estimates to be reasonable.

Notice that the cost of the reduced schedule as estimated by DIW Econ (2015c) is based on the current ferry service and on cost data from 2014. We account neither for possible future cost reductions through technological improvements like electrical operation, nor for an extensive adjustment of the underlying business model including the offered onboard services. Instead, we focus on the two most universal factors: schedule and price. For further details of the cost model, see DIW Econ (2015c).

Market segmentation. In the theoretical model, we consider one single market in which ferry and tunnel offer differentiated products. Yet, different vehicles cross the Fehmarn Belt. Each can be treated as a separate market. We account for two markets: cars and lorries. Combined, they represent the vast majority of current and forecasted traffic.

- When the ferry chooses to compete, it competes in both markets. It uses the very same ships for transporting cars and lorries, so it serves

[13] According to information provided by Scandlines representatives, the ferry operator plans to serve the Fehmarn Belt with four ships at daytime (three during off-season) and two ships at night.

both markets with the same frequency f. The semi-fixed cost $C_F(f)$ covers both car and lorry transport. In order to calculate the profit of the ferry we first sum the revenues from both markets. Then we subtract the marginal costs, accounting for both cars and lorries. Finally, we subtract the semi-fixed cost determined by the ferry schedule.

- In the competition subgame, ferry and tunnel each choose two prices, one for cars and one for lorries. We assume that prices in one market do not affect demand in the other market.
- We use equation (10) and (11) to separately calculate the equilibrium prices for cars and lorries. The equations are valid for both markets, but the parameters differ. In particular, parameters θ_i (and thus $\bar{\theta}w(f)$), δ and c_F are different, as detailed in the Appendix. We are not aware of any specific data or forecast of the elasticity. Therefore, we simply assume that both markets feature the same elasticity ϵ.

Essentially, we choose a ferry schedule (frequency f) that provides sufficient capacity and then determine the equilibrium of the competition subgame for the two respective markets. Next, we calculate whether the revenues from the two markets combined suffice to cover ferry costs. If so, we conclude that the ferry chooses to compete, otherwise the stage games result in a monopoly for the tunnel.

6. Results

In the introductory section, we pose two research questions:

1. Will the tunnel induce the ferry to exit the market once it operates?
2. Will the toll revenues cover all costs of constructing and operating the tunnel?

We know from theory that the ferry will exit the market if its profits in the competition subgame are negative. It will compete if profits are positive. In the following paragraphs, we first present the outcome of the competition subgame, then the outcome of the monopoly subgame. We conclude with the outcomes of the stage games and the repeated game as a whole, which provide answers to the research questions. We show that these answers depend on an assumption about the elasticity of demand. All results are denoted in 2014 price levels.

Outcome of the competition subgame. Table 1 reports the results of the competition subgame equilibrium. The elasticity assumptions turn out to be crucial. With low elasticity (cases A and B), the ferry generates positive profits. Its market shares range around 30 percent. To achieve this, the ferry significantly lowers its prices compared to the reference prices of 65 Euro/car and 267 Euro/lorry. The slump is particularly striking for lorries. The tunnel charges higher prices than the ferry. Its car price is above the reference value, its lorry price is significantly below.

With high elasticity (case C), ferry profits in the competition subgame are negative. Prices are much lower than in cases A and B. This is not surprising: For the tunnel, cutting prices is more attractive in case C than in cases A or B, because a lower price not only increases the tunnel's market share, but also stimulates overall demand significantly.

The net present value of the tunnel project, calculated over a 50-year period, is negative in all cases; operational revenues are not sufficient to repay construction debt. Losses are highest in case B, approaching one billion Euro. A negative net present value implies that the tunnel will still be in debt after 50 years of operation. In fact, according to our calculations, it will take the tunnel more than 64 years to fully repay its dept.

Table 1: Equilibrium outcome in the competition subgame

Outcome			Case A $\epsilon = 0$	Case B $\epsilon = 0.1$	Case C $\epsilon = 0.6$
Ferry					
Price	car	(Euro)	44	42	29
	lorry	(Euro)	67	63	44
Market share	car	(%)	32	30	15
	lorry	(%)	30	28	14
Annual net result		(million Euro)	17	6	- 18
Tunnel					
Price	car	(Euro)	84	78	52
	lorry	(Euro)	118	110	73
Market share	car	(%)	68	70	85
	lorry	(%)	70	72	86
Net present value		(million Euro)	- 706	- 936	- 259

Note: values are rounded.

Outcome of the monopoly subgame. In case C, the ferry incurs losses from competing (table 1). Consequently, it does not compete in equilibrium. Instead, the tunnel enjoys a monopoly in every period. Calculating the exact monopoly prices would require additional optimizations that would be highly influenced by demand elasticities. Also, it is not clear whether the publicly owned tunnel operator actually intends to optimize revenue as long as all cost are covered. In fact, the official website claims that "the company is not intended to make profits for the owner"[14], and according to Femern A/S (2016, p. 66), the final tunnel prices will be determined by the Danish Minister for Transport and Building. Given this uncertainty, our calculations are based on the reference prices, because these prices are used by Femern A/S (2016) for their financial analysis.

As shown in table 2, over a 50-year period, the net present value of the tunnel project is about 3.9 billion Euro, including EU grants which cover 10 percent of building costs. Hence, if there is no competition and the traffic forecasts turn out to be valid, the project can be sustained as a profitable business. In this case, the repayment period will be comfortably below the 50-year threshold.[15] The results also imply that if the ferry exited, the tunnel could reduce its prices and would still be profitable.[16]

Table 2: The tunnel's monopoly payoff with reference pricing

Outcome		Unit	Value
Tunnel price (reference price)	car	(Euro)	65
	lorry	(Euro)	267
Tunnel market share	car	(%)	100
	lorry	(%)	100
Tunnel net present value		(million Euro)	3 897

Note: values are rounded.

Demand reactions. In order to evaluate which of the three cases seems more likely, we investigate the demand reactions associated with the equilibrium out-

[14]http://femern.com/en/Tunnel/Finance/Ticket-prices-in-the-Fehmarnbelt-tunnel.

[15]According to our model it will take the tunnel only 24 years to repay its debt, while Femern A/S (2016) expects a longer period. This emphasises that we used rather favorable assumptions in an effort not to underestimate tunnel profitability.

[16]In fact, in order to just break even within 50 years the tunnel could go as low as 44 Euro/car and 181 Euro/lorry (assuming constant demand). One should note, however, that our methods tend to overestimate tunnel profitability (see section 5 and footnote 15).

come in the competition subgame. In doing so, the monopoly subgame serves as a reference, because prices equal the values assumed by the tunnel operator (Femern A/S, 2016) and traffic volumes (car and lorry market size) equal the official forecasts based on Intraplan and BVU (2014) as detailed in tables B.5 and B.8 in the appendix.

When we compare the reference traffic volume with traffic volume in the competition subgame, we find that the scenario with higher elasticity ($\epsilon = 0.6$) implies a fairly strong demand reaction: the car market becomes 14 percent larger than the reference traffic volume; the lorry market even increases by 117 percent. In the inelastic case ($\epsilon = 0.1$), the car demand shrinks by two percent; the lorry market increases by nine percent. In the case with $\epsilon = 0$, by definition the car and lorry market size equals the reference traffic volume. Judging from the demand reaction, the inelastic case seems more realistic. But there is no direct empirical evidence to support this assessment. Still, we consider it more likely that elasticity will be low.

Outcome of the stage game and the repeated game. Referring to the research question, the findings are as follows:

1. If the elasticity of demand is low ($\epsilon = 0$ or $\epsilon = 0.1$), the ferry will not exit the market. Instead, it will compete with the tunnel in every period. If the elasticity is high ($\epsilon = 0.6$), the ferry will exit the market immediately (tables 1 and 3).
2. If the ferry competes, the tunnel will not be able to repay its debt over a 50-year period. Revenues from the first 50 years of operation will be too low to cover building and operational costs. In contrast, if the ferry exits, the tunnel will generate sufficient revenues to cover all cost (tables 1 and 2).

As detailed in the preceding paragraph, the inelastic cases seem more likely. Consequently, there is a high chance that the ferry will compete and that the tunnel will be under competitive pressure.

7. Discussion

We find that it is quite likely that the ferry will stay in the market and that if it stays, the tunnel will not be able to repay its debt within the first 50 years of operation. These findings are at odds with previous reports. In their traffic forecast, Intraplan and BVU (2014) include a scenario which assumes continued

Table 3: Equilibrium outcome of the stage games and the repeated game

Outcome	Case A $\epsilon = 0$	Case B $\epsilon = 0.1$	Case C $\epsilon = 0.6$
Ferry action	compete	compete	not compete
Market structure	duopoly	duopoly	monopoly
Tunnel NPV	negative	negative	positive

ferry service, but state that it is "very doubtful that operating a parallel ferry, (...), will be economically feasibility[sic]" (p. 174). They argue that ferry revenues will sharply decrease after tunnel opening, but their report provides no discussion of ferry costs. Our results confirm that ferry revenues decrease[17], but the analysis of cases A and B also show that when cost reductions are accounted for, ferry operations can nevertheless be profitable. Our cost reduction estimates are based on historical data. Additional future cost reduction of ferry operation would further strengthen the business case of the ferry.

The tunnel operator's financial analysis is based on the traffic forecast by Intraplan and BVU (2014) and includes the case of continued ferry service as a sensitivity scenario. Femern A/S (2016) calculates that a permanent 1-hourly or 2-hourly ferry service would significantly reduce tunnel revenue compared to the tunnel-only scenario, but that the Fixed Link would still manage to repay all debt within 50 years. In contrast, our results indicate that 50 years will not suffice to break even if the ferry competes. Two main factors account for the difference: prices and market shares. Intraplan and BVU (2014) assumes that a continued ferry service charges 49 Euro per car and 200 Euro per lorry, while the tunnel maintains the reference prices of 65 Euro for cars and 267 Euro for lorries (2014 prices). According to Femern A/S (2016), this reduces the traffic on the Fixed Link by 10 to 15 percent compared to the tunnel-only scenario. Neither Intraplan and BVU (2014) nor Femern A/S (2016) provide in-depth reasoning for such price setting, other than the undisputed expectation that competitive ferry prices must be lower than tunnel prices. In contrast, our game-theoretic approach delivers a model-based prediction of strategic price setting in the case

[17] According to KPMG (2016) the ferry business of the Fehmarn Belt generated revenues of 103 million Euro from cars and 67 million Euro from cargo in 2015. According to our model, equilibrium revenues after tunnel opening are considerably lower: In case B they amount to a total of just 72 million Euro.

of competition. We find that the tunnel charges less than half of the reference price for lorries and a somewhat higher price for cars. It only reaps 70 percent of the market share. Tunnel revenues under competition are thus much lower than under the assumption of Intraplan and BVU (2014) and Femern A/S (2016), which explains the difference in tunnel profitability.

Restricted price setting. Price setting in our model (competition subgame) is based on profit-optimising behaviour and is influenced only by demand conditions and competitive forces. The actual tunnel prices, however, will be determined by a political process. As such, additional considerations might influence prices. On the one hand, after its opening, politicians are committed to the tunnel and could seek to guarantee its success in terms of high usage. In fact, once the building costs have been incurred, lowering prices to maximise usage might be optimal from a welfare perspective, as it increases aggregate surplus. Such considerations could induce the tunnel to further reduce its prices and might make a competing ferry non-profitable. On the other hand, politicians might be reluctant to charge prices that differ greatly from the currently announced reference prices; legal requirements could also restrict the price setting. Thus, the tunnel's lorry prices might well be less aggressive than indicated by our analysis, while the car prices might be somewhat lower. This could allow the ferry to keep much higher lorry prices but would also drive down its car prices (compared to the result in table 1). Overall, the ferry would probably benefit from such a price regime.

Collusion. In our model, we assume that tunnel and ferry behave as competitors. As a result, the ferry either exits the market or the tunnel incurs losses. But what if the players try to collude and collectively fix prices? This is in fact a possibility. If, for instance, the tunnel charges the reference prices of 65 Euro per car and 267 Euro per lorry, and the ferry sets prices at 45 Euro/200 Euro, then both the tunnel and the ferry would be profitable: The annual profits of the ferry would be 33 million, and the tunnel's net present value would be 660 million. Both players would be better off compared to the equilibrium of the competition subgame. Yet, it is hard to predict whether tunnel and ferry would be able to sustain such a cartel. First, both parties would typically have an individual incentive to deviate from price fixing. In particular, the tunnel might choose to compete aggressively in order to force the ferry to exit. Second, competition law prohibits such a price fixing scheme – proving its existence, however, is a difficult task.

Total welfare. Which implications follow for the overall evaluation of the tunnel project? Our results suggest that the tunnel will not be a bankable business if the ferry stays. But it may still be worthwhile from an overall welfare perspective. In particular, users will benefit from time savings and, in the case of competition, from lower prices. In addition, the ferry operator might face increased incentives to upgrade and modernize its vessels, reflecting developments on the Channel Tunnel (Anguera, 2006). All of this will increase consumer surplus. The question is whether the positive effects justify the high costs of building the tunnel, and the environmental side effects associated with the construction. Incentive (2015) analyses the total costs and benefits of the Fehmarn Belt Fixed Link and concludes that the benefits to society are positive and amount to 3.5 billion Euro (net present value over 50 years), corresponding to an internal rate of return of 5.0 percent. Incentive (2015) assumes that the ferry exits the market, but includes a sensitive analysis with continued (but non-optimal) ferry operation. This reduces the internal rate of return to 4.1 percent. DIW Econ (2015c, Chapter 3) examines how the cost-benefit analysis of Incentive (2015) changes if (a) building costs are updated and (b) the ferry responds optimally to the tunnel. The report concludes that the benefits to society are positive, but amount to just 310 million Euro – a reduction by a factor of more than 10 compared to Incentive's main result. In addition, DIW Econ (2015c, Chapter 3) points out that the costs for building a new bridge connecting the island of Fehmarn with the mainland are not included in the analysis. Doing so would increase the costs of the project by 250 to 600 million Euro. But it is unclear whether such a bridge should be considered part of the project; some argue that this bridge has to be rebuilt in any case.

8. Conclusion

In this paper, we analyse competition between the future Fehmarn Belt Fixed Link and a ferry operator serving the same route between Denmark and Germany. We develop a model which is tailored to the Fehmarn Belt case but could be applied to other transportation duopolies with heterogeneous goods and asymmetric cost structures. Simplicity is a distinct feature of the route choice model. It allows us to embed the route choice into a multi-stage, game-theoretic setup. This way, we are able to study the strategic interaction of two transportation service providers. In particular, the model combines simultaneous price competition with strategic exit and entry decisions. It uses Nash equilibrium as the solution concept.

We calibrate the model using real-world data as well as forecasts on the future traffic volumes. Our results vary with the assumption on demand elasticity. If the elasticity is low, the ferry will compete with the tunnel and secure a positive profit. If the elasticity is high, the ferry anticipates to incur losses and will not compete. We lack valid data on the elasticity parameter but consider the low-elasticity scenario to be more likely. This is worrying news for the tunnel, because we also show that if the ferry competes, the tunnel project will not be profitable. The reason is that price competition is fierce and a competing ferry operator obtains about 30 percent market share, significantly cutting into the tunnel's expected revenue stream.

Our findings challenge previous evaluations concerning the commercial viability of the Fixed Link (Intraplan and BVU, 2014; Incentive, 2015; Femern A/S, 2016). Our results indicate that the ferry is a much stronger competitor to the planned tunnel than previously suggested, and that one should not take it for granted that the ferry will exit the market. There is a risk that the Fehmarn Belt Fixed Link will end up suffering the same fate as the Channel Tunnel, which also underestimated the influence of strong ferry competition and never fully realized the formerly projected revenues.

Appendix A. Equilibrium of the repeated game

The *repeated game* begins after the opening of the tunnel, at $t = 0$, and continues infinitely. Starting in $t = 1$, there is a series of *stage games* that repeat every period as detailed in section 3 and depicted in figure 1. Each stage game starts with the ferry deciding whether to compete or not. If the ferry does not compete, the tunnel is the single provider and there is a monopoly. If the ferry competes, a *competition subgame* begins, in which the ferry chooses a frequency, and both tunnel and ferry set prices (see section 3). This concludes the stage game.

The payoff of the repeated game is the discounted sum of all stage game payoffs. We assume a common discount factor less than one. Section 4 characterises the equilibrium of the competition subgame and the stage game. Intuition suggests that the ferry will never compete on the market if the competition subgame results in a negative profit. If, on the other hand, the competition subgame is profitable for the ferry, then it should compete in every period. The following proposition confirms this intuition.

Proposition 1. *(1) If the competition subgame has a subgame perfect equilibrium with positive ferry profits, then there is a subgame perfect equilibrium of the repeated game in which the ferry competes in every period.*

(2) If the competition subgame has a subgame perfect equilibrium with negative ferry profits, then there is a subgame perfect equilibrium of the repeated game in which the ferry does not compete in any period.

Proof. Let $s(t) = (s_F(t), s_T(t))$ be a strategy profile of the stage game in period t, and $S = \{s(t)\}_{t=1}^{\infty}$ be a history-independent strategy profile of the repeated game. Let P_T^M be the monopoly price of the tunnel.

(1) Let $(P_F^*, P_T^*(c), f^*)$ be a subgame perfect equilibrium of the competition subgame inducing positive ferry profits. Then the following strategy profile s^* constitutes a subgame perfect equilibrium of the stage game: The ferry competes, i.e., $a^* = c$; $(P_F^*, P_T^*(c), f^*)$ is the strategy profile in the competition subgame; $P_T^*(nc) = P_T^M$ is the off-equilibrium tunnel price.

Next, consider the following strategy profile S^* of the repeated game: in every period t, tunnel and ferry play according to s^*. To show that this profile constitutes a subgame perfect equilibrium, we need to show that there is no profitable one-shot deviation for any player. Assume the contrary. Then there is some period t such that a unilateral deviation from s^* is profitable, i.e., it yields a higher payoff in period t or any later stage. As strategy profile S^* is history-independent, a higher payoff must occur in the very same period t. But if such a deviation exists, s^* cannot be an equilibrium of the stage game; hence, a contradiction.

(2) Let $(P_F^*, P_T^*(c), f^*)$ be a subgame equilibrium of the competition subgame inducing negative ferry profits. Then, the following strategy profile s^* constitutes a subgame perfect equilibrium of the stage game: The ferry does not compete, i.e., $a^* = nc$; $(P_F^*, P_T^*(c), f^*)$ is the off-equilibrium strategy profile in the competition subgame; $P_T^*(nc) = P_T^M$ is the equilibrium tunnel price. The rest of the proof proceeds analogously to (1). □

In the application, we consider a finite rather than an infinite horizon. Using backward induction, one can easily show that Proposition 1 holds also for a finite version of the repeated game.

Appendix B. Parameters of the empirical analysis

Table B.4 lists the parameters used to calculate the net present value of the tunnel project. Table B.5 lists the parameters relating to overall demand. Table B.8 lists the traffic forecast timeseries.

Table B.6 lists the parameters used to calculate the difference in journey time, and table B.7 lists the parameters to calculate the average value of time, $E[\theta_i]$. The average monetary advantage, calculated as the average difference in journey time times the average value of time, is 52.40 Euro for cars and 67.89 Euro for lorries.

A note on value added taxes: The ferry is exempt from value added tax. The tunnel price for lorries is stated as the net-of tax price (as lorries can deduct these taxes). The tunnel price for cars, in contrast, includes a 19 percent value added tax (see DIW Econ, 2015c).

Table B.4: Parameters to calculate the net present value of the Fehmarn Belt Fixed Link

Parameter	Unit	Value
Basics		
- time horizon	(years)	50.00
- discount rate	(%)	3.00
Construction costs		
- coast-to-coast section	(billion Euro)	7.00
- danish landworks	(billion Euro)	1.27
Yearly operating costs		
- coast-to-coast section	(million Euro)	62.75
- danish landworks	(million Euro)	32.04
EU funding		
- coast-to-coast section	(%)	10.00
- danish landworks	(%)	10.00
Annual secondary revenues		
- railway	(million Euro)	53.63
- bus	(million Euro)	10.33

Notes and source: All values are from Femern A/S (2016), are in 2015 prices and are based on the average annual exchange rate of 2015 (Eurostat, 2016). Exception: annual bus revenues are the authors' calculations based on Intraplan and BVU (2014); Incentive (2015). Construction costs include reserves and assume commencement of construction at the beginning of 2018 and opening in mid 2026. Some values are rounded.

Table B.5: Parameters relating to demand and market shares

Parameter	Unit	Cars	Lorries	Source
Traffic at reference price (D_0)	(yearly avg.)	4 739 909	796 823	(1)
Reference price (P_{T0})	(Euro)	65	267	(2)
Ferry's max. market share (δ)	(%)	85	80	(3)
Ferry's capacity per ship		124	35	(3)

Sources: (1) Yearly average over the first 50 years of tunnel operation (2026-2076), based on the traffic forecast timeseries from table B.8. (2) Intraplan and BVU (2014); (3) DIW Econ (2015c).

Table B.6: Parameters to calculate total crossing time

Parameter	Unit	Tunnel	Ferry	Source
Pure journey time	(minutes)	15	45	Intraplan and BVU (2014)
Check-in/out	(minutes)	2	15	Intraplan and BVU (2014)
Avg. waiting time	(minutes)	0	40	DIW Econ (2015c)
Total journey time	(minutes)	17	100	

Notes: The average waiting time applies to the equilibrium schedule in cases A and B: It implies that the average waiting time for the ferry is 30 minutes during daytime and one hour during night-time. The stated value is a weighted average based on the share of customers during daytime and night-time, respectively. The shares are the authors' calculations, using information provided by Scandlines ApS. Average waiting time for the ferry is rounded.

Table B.7: Parameters to calculate the average value of time

Parameter	Unit	Value	Source
Cars			
Average value of time per person per hour	(Euro)	15.00	(1)
Average number of persons per car		2.54	(2)
Average value of time per car per hour ($E[\theta_i]$)	(Euro)	38.11	
Lorries			
Average value of time per transported ton per hour	(Euro)	4.27	(3)
Average freight volume per lorry	(ton)	11.56	(4)
Average value of time per lorry per hour ($E[\theta_i]$)	(Euro)	49.38	

Sources: (1) Intraplan and BVU (2014, Table 6-8 and Annex, Table 3-27); (2) Intraplan and BVU (2014, p. 85); (3) Authors' calculations based on Heatco (2006); (4) Intraplan and BVU (2014, Figure 6-2 and 6-3).

Table B.8: Traffic forecast timeseries

Year	Cars	Lorries	Year	Cars	Lorries
	(thousand)			(thousand)	
2014	1542	425	2033	4071	697
2015	1659	418	2034	4148	706
2016	1704	430	2035	4211	715
2017	1751	443	2036	4274	722
2018	1796	456	2037	4337	731
2019	1842	469	2038	4399	740
2020	1887	482	2039	4464	749
2021	1933	495	2040	4527	758
2022	1980	508	2041	4591	767
2023	2028	522	2042	4651	776
2024	2078	536	2043	4711	785
2025	2128	551	2044	4768	794
Tunnel opens			2045	4826	801
2026	3177	617	2046	4880	810
2027	3423	632	2047	4934	819
2028	3614	646	2048	4983	828
2029	3763	661	2049	5033	837
2030	3840	670	2050	5083	846
KPMG data ends			2051	5135	855
2031	3917	679	⋮	⋮	⋮
2032	3994	688	2075	5135	855

Notes and source: Intraplan and BVU (2014) provides the basis traffic forecast for the Fixed Link. Since the publication of their forecast, tunnel opening has been postponed by four years. KPMG (2016, p. 59) provides traffic volumes accounting for the delay, but reports values only up to 2030. For our analysis, we need a full time series covering 50 years of tunnel operations. We use KPMG's time series for all values up to 2030. To calculate the values after 2030, we apply growth rates provided by Intraplan and BVU (2014). The forecast by Intraplan and BVU (2014) stops 25 years after the tunnel opening. In accordance with Incentive (2015), we make the simple assumption that traffic is constant afterwards (2051–2075). Values are rounded.

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