DIW BERLIN

1539

Discussion Papers

Deutsches Institut für Wirtschaftsforschung 2016

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IMPRESSUM

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ISSN electronic edition 1619-4535

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

Rafael Aigner*

January 2016

Abstract

The Fehmarn Belt is a strait between Denmark and Germany, currently served by a ferry. This note analyses the theory of competition between the ferry and a planned tunnel, the Fehmarn Belt Fixed Link. The model is an asymmetric duopoly and addresses 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? To complement the theoretical analysis, the note provides results of a numerical application.

Keywords: Fehmarn Belt Fixed Link, transportation economics, competition analysis, route choice, asymmetric duopoly

JEL classification: R42, D43, L91

*A previous version of this note was prepared as a supplement to a report by DIW Econ (2015c) commissioned by Scandlines ApS. The author thanks Michael Arnold, Pio Baake, Ferdinand Pavel, Thure Traber and Katharina Weber for valuable comments and discussions, as well as participants of the 2015 conference Verkehrsökonomik und -politik, Berlin.
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1 Introduction

The Fehmarn Belt is a strait between the German island of Fehmarn and the Danish island of Lolland. Currently, a ferry operator connects the two islands. Denmark plans to build a fixed link in the form of a tunnel which could reduce travelling time by about one hour compared to the ferry. The cost associated with building and operating the tunnel shall primarily be paid for by revenues from user tolls; in this sense the Fehmarn Belt Fixed Link shall operate as a profitable business.[1] Studies and forecasts commissioned by the tunnel find that the tunnel will manage to do so, but by just a tiny margin (Femern A/S, 2014; Incentive, 2015; Intraplan/BVU, 2014). These studies typically assume (a) that the tunnel tolls match the current ferry prices and (b) that the ferry will exit the market once the tunnel is build.[2] In two recent statements, DIW Econ (2015a,b) questions these assumptions, noting in particular that appropriate ferry reactions are not sufficiently accounted for in previous studies. Yet, for any assessment of the tunnel's economic viability it is crucial to anticipate the competitive equilibrium of the ferry-tunnel duopoly.

In this note, we 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 cost of constructing and running the tunnel?

In a related study, DIW Econ (2015c) calibrates and applies the model. It concludes that the assumptions of previous studies might turn out wrong; the ferry constitutes a significant competitive force and threatens the tunnel's profitability.

2 Model

The model is a one-shot game starting after the opening of the tunnel. It is designed to be simple and to have low data requirements. A more sophisticated analysis would require both a more complex theory and extended data collection.

[1] Apart from toll revenues, the Fixed Link is also expected to receive EU grands.

[2] In fact, these studies include a sensitivity analysis which assumes reduced but continued ferry operations. But these specific scenarios do not seem very likely because they are not derived from any form of optimal behaviour. They are not part of the studies' main results either.

Consider the market for cars crossing the Fehmarn Belt. Suppose for a moment that the tunnel is the only way to cross the belt and that the tunnel charges a fixed price P_T. Let $D(P_T)$ be total demand for crossings.[3] Will the ferry enter into this market?

Ferry demand Suppose the ferry does enter the market and offers a price of $P_F < P_T$. Assume that the supply of the ferry does not increase the total demand for crossing, i.e., all the ferry's customers are switching from the tunnel.[4] Also, suppose the only difference between ferry and tunnel is the crossing time, which is longer for the ferry. Let w be the difference in crossing times. This value includes all time-relevant differences like journey/sailing duration, check-in/out times, as well as the average waiting time for the next ferry. For now, w is a fixed parameter.

The time saved when taking the tunnel rather than the ferry translates into a *monetary advantage* that the tunnel has over the ferry. Passengers are heterogeneous in this respect. Let θ_i be passenger i's value of time. Then the monetary advantage of the tunnel as perceived by passenger i amounts to $\theta_i w$. He or she takes the ferry rather than the tunnel if

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

Let δ be the share of private passengers and $(1-\delta)$ be the share of business passengers. We assume that business passengers' value of time is so high that they would never take the ferry (for any reasonable price difference). For private passengers, we assume that the share of passengers with time value θ_i is uniformly distributed between 0 and $\bar{\theta}$. Hence, the share of private passengers taking the ferry given prices P_F and P_T is[5]

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

[3] Assume D is decreasing and continuously differentiable.

[4] This assumption reduces the reliance on estimates for certain (cross)-price elasticities. This makes the model's predictions more robust. Estimating additional ferry demand is difficult. By means of this assumption we ensure that our results are not driven by some too optimistic additional ferry demand.

[5] 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.

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

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

3 Ferry's best response

Now suppose ferry and tunnel are both active on the market. Again, let P_T be the tunnel price. To model the ferry's best response to price P_T, we consider three time horizons:

Short term. Defined as the time frame in which the ferry can only change its pricing.

Medium term. Defined as the time frame in which the ferry can change prices and frequency, as detailed below. It could stop servicing customers but would not be able avoid the fixed cost associated with being a shipping company and maintaining the necessary infrastructure.

Long term. Defined as the time frame in which the ferry can change prices and frequency as well as exit the market. Market exit is equivalent to a payoff of zero with neither revenues nor cost.

3.1 Short-term best response

In the short run, the ferry can only change its price P_F. Suppose it incurs marginal cost of c_F per unit. Given tunnel price P_T, the ferry sets a price in order to maximise short-term net revenues R_F:

$$R_F(P_F, P_T) = (P_F - c_F)\delta \frac{P_T - P_F}{\bar{\theta} w} D(P_T) \tag{4}$$

The net-revenue-maximising price is

$$P_F^* = \frac{P_T + c_F}{2} \ . \tag{5}$$

Put differently, the ferry optimizes short-term profits by choosing as its price the average of its marginal cost and the tunnel price. Its optimized market share will be

$$\frac{\delta}{2} \frac{(P_T - c_F)}{\bar{\theta} w} \ . \tag{6}$$

3.2 Medium- and long-term best response

In the medium and long term, the ferry can not only set prices but also change the frequency f of its service; i.e., it can specify both the number of ships in operation and their schedule. A typical schedule, for instance, has four active ships making continuous round-trips. This results in a frequency of two ferry departures per hour, i.e., at each port a ship leaves every 30 minutes. So, for the sake of concreteness, think of the frequency as a number, representing the number of regular ferry departures per hour.[6] As there is only a limited number of reasonable schedules, we assume that frequency is a discrete choice. 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 costs of ferry operation consist of three elements: *fixed* costs, *variable* costs, and *marginal* costs. Fixed cost are, well, fixed. They cover aspects like the port infrastructure and general management. Variable costs refer to all cost elements that change with the selected schedule and frequency but do not increase with additional (marginal) passengers.[7] The variable cost component increases, in particular, with the number of ships in operation and the number of trips per ship. Marginal costs refer to incremental costs induced by additional (marginal) passengers. They amount to c_F per transported unit (e.g. cars). The *semi-fixed* cost C_F combine fixed and variable cost and are a function $C_F = C_F(f)$ of the frequency. A frequency of $f = 0$ represents a schedule with no active shipping (i.e., zero ships per hour). So $C_F(0)$ equals the fixed cost. Generally, the higher the frequency f, the higher are semi-fixed cost $C_F(f)$.

(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. In the medium- and long-term, 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

[6] 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.

[7] 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. Nevertheless, in any application this must be accounted for; eventually an outcome can only be feasible if demand is below capacity.

with this frequency. Then the *medium-term profits* of the ferry are

$$\pi_F = (P_F - c_F)\delta \frac{P_T - P_F}{\bar{\theta} w(f)} D(P_T) - C_F(f)\,. \tag{7}$$

Medium term In the medium term, the ferry chooses a frequency f as well as a price P_F in order to maximise profit π_F. The optimisation of the ferry can be decomposed into two steps:

1. For any given frequency f, solve for the short-term optimal price P_F^*. Then calculate the resulting profits, denoted by $\pi_F^*(f, P_T)$.
   Note that P_F^* does not depend on f, but π_F^* does.

2. Choose a frequency f in order to maximise $\pi_F^*(f, P_T)$.

Let $f^*(P_T)$ denote the profit-maximising frequency.

Long term In the long term, the ferry has an additional option: market exit. When the best medium-term profit is negative, the ferry will sooner or later exit the markets. Hence, the long-term best response market share of the ferry is

$$s_F^*(P_T) := \begin{cases} \dfrac{\delta}{2} \dfrac{(P_T - c_F)}{\bar{\theta} w(f^*(P_T))} & \text{if } \pi_F(f^*(P_T), P_T) > 0 \\ 0 & \text{if } \pi_F(f^*(P_T), P_T) \leq 0 \end{cases}\,. \tag{8}$$

4 Tunnel strategies

Let the cost of building and operating the tunnel be a fixed value of C_T.[8] The marginal costs of the tunnel are zero. Once build, the fixed cost is sunk and the tunnel chooses a price P_T in order to maximise revenues R_T. The tunnel is *ex ante profitable* if revenues R_T exceed cost C_T.

4.1 Stackelberg competition

Suppose the tunnel is a Stackelberg leader, i.e., it can choose its price and commit to it. Afterwards, the ferry follows and chooses its long-run best response. The tunnel is able to anticipate both the ferry price and whether or not the

[8]The tunnel operators expect to receive a EU grant of about 1.4bn Euro to support building the tunnel (Femern A/S, 2014). If such grants shall be accounted for, they reduce parameter C_T. Put differently, C_T is the part of total cost that users rather than European tax payers must pay for.

ferry will exit the market. The tunnel chooses its price P_T in order to maximise its revenues $R_T(P_T)$:

$$R_T(P_T) = [1 - s_F^*(P_T)]D(P_T)P_T \; . \tag{9}$$

The major effects driving the optimal choice of P_T are:

- Higher P_T means higher revenues per unit.
- Lower P_T increases overall demand D and – ignoring potential changes in ferry frequency – the tunnel market share increases, too.
- At some price P_T, there is a discontinuity: Prices below a certain threshold induce the ferry to exit the market and secure the tunnel a 100 percent market share.

Let P_T^{SB} be the Stackelberg price that maximises revenue. We can now refer back to the question posed in the Introduction. If the tunnel has the power to act as a Stackelberg leader then:

1. The tunnel will induce the ferry to exit the market if $\pi_F^*(f^*(P_T^{SB}), P_T^{SB}) \leq 0$.
2. The tunnel is ex ante profitable if $R_T(P_T^{SB}) \geq C_T$.

4.2 Bertrand competition

We now move from the sequential choice Stackelberg game to a simultaneous move game. We analyse three related games: short term, medium term, and long term. The tunnel's action set is the same in all three: it sets its price P_T. The ferry's action sets differ. In the short-term game, frequency f is fixed and the ferry only sets its price. In the medium-term game, the ferry is free to set both price P_F and frequency f. In the long term, the ferry can additionally choose to exit the market.

Short-term equilibrium Fix some ferry frequency f. Then a pair of prices (P_F, P_T) is a *short-term equilibrium* if P_F maximises ferry short-term net revenue R_F (given P_T and f), and P_T maximises tunnel revenues

$$R_T = \left[1 - \delta \frac{P_T - P_F}{\bar{\theta} w(f)}\right] D(P_T)P_T \; . \tag{10}$$

Solving for the equilibrium prices is a straightforward exercise. We already know the ferry's optimal price given the price of the tunnel, see equation (5). For notational convenience, define $\bar{v} := \bar{\theta} w(f)$. Then the tunnel's best response is

$$P_T^* = \frac{\bar{v}/\delta + P_F}{2 - \epsilon}(1 - \epsilon) \; , \tag{11}$$

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

It now follows that the equilibrium prices are

$$P_T^{EQ} = \frac{(1-\epsilon)(c_F + 2\bar{v}/\delta)}{3-\epsilon} \; , \tag{12}$$

$$P_F^{EQ} = \frac{(2-\epsilon)c_F + (1-\epsilon)\bar{v}/\delta}{3-\epsilon} \; . \tag{13}$$

Medium-term equilibrium In the medium term, the ferry can change its price and its frequency. A *medium-term equilibrium* consists of a pair of prices (P_F, P_T) and a frequency f such that:

- Prices (P_F, P_T) form a short-term equilibrium given f.
- Frequency f is the ferry's medium-term best response to tunnel price P_T, i.e., $f = f^*(P_T)$.

In the medium term, the ferry's payoff may be negative as fixed cost could exceed revenues.

Long-term equilibrium In the long run, the ferry can exit the market resulting in a payoff of zero. The tunnel is able to condition its pricing on the ferry's exit decision. A (pure strategy) *long-term equilibrium* consists of

- a ferry action $a \in \{stay, exit\}$ determining whether or not the ferry exits the market,
- a ferry price P_F and a frequency f, and
- a conditional tunnel price $P_T(a)$,

such that:

- $(P_F, P_T(stay), f)$ constitute a medium-term equilibrium.
- $P_T(exit)$ maximises the tunnel's monopoly revenue $D(P_T)P_T$.

- The ferry exit decision is a best response, i.e., $a = exit$ if ferry profits in the medium-term equilibrium $(P_F, P_T(stay), f)$ are negative, and $a = stay$ otherwise.

The outcome of the long-term equilibrium depends on the ferry's profits in the medium-term equilibrium. Referring back to the principal question, we can summarize the consequences of the long-term equilibrium:

1. If medium-term equilibrium ferry profits are positive, the ferry will stay in the market. Whether or not the tunnel is ex ante profitable depends on its revenues in the medium-term equilibrium.

2. If medium-term equilibrium ferry profits are negative, the ferry will exit the market in the long run. Once the ferry exits, the tunnel can charge monopoly prices. The ferry anticipates that the tunnel can revert back to Bertrand-pricing upon ferry-reentry and thus stays away from the market. Whether or not the tunnel is ex ante profitable depends on its monopoly revenues.

5 Application

A recent report by DIW Econ (2015c) uses the model outlined in this note and calibrates it with real-world data as well as forecasts. The report complements former studies on the Fehmarn Belt Fixed Link and challenges previous results about the economic viability of the tunnel. In this note, we briefly outline extensions and modifications used by DIW Econ (ibid.). Then we summarize the report's main findings. For a more detailed description of the empirical analysis and its results, please refer to the report directly (in German).

5.1 Demand

Current studies supporting the tunnel (Femern A/S, 2014; Incentive, 2015) are based on the traffic forecast by Intraplan/BVU (2014). The forecast presumes that the tunnel charges tolls similar to the current ferry prices. Given these reference tolls, Intraplan/BVU (ibid.) reports the forecasted traffic volumes for the Fehmarn Belt. We use the reported tolls and traffic volume as a reference and denote them by P_{T0} and D_0, respectively.

To keep it simple, we assume that demand function $D(P_T)$ is represented by

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

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 such that demand satisfies the reference values reported by Intraplan/BVU (2014), i.e.,

$$\alpha := \frac{D_0}{P_{T0}^{-\epsilon}} \tag{14}$$

As we do not know an exact value for ϵ, we consider different scenarios, varying the elasticity.

5.2 Market segmentation

Until now, we have considered one single market in which ferry and tunnel offer differentiated products. But the Fehmarn Belt is crossed by different vehicles categories. Each can be treated as a separate market. In the application, we consider two markets: cars and lorries. Combined, they represent the vast majority of current and forecasted traffic. We assume that prices in one market do not affect demand in the other market.

The extension of the model to the case of two separate markets is mostly straightforward, which is why we do not detail on it. The basic principles are:

- Tunnel and ferry choose distinct prices for lorries and cars, respectively. Market shares of ferry and tunnel typically differ for cars and lorries.
- The following parameters typically differ for cars and lorries, respectively: value of time θ_i (and thus $\bar{\theta}w(f)$), share δ of the relevant passenger groups, ferry's marginal cost c_F, and demand D, i.e., both elasticity ϵ and scaling parameter α.
- As the ferry uses the very same ships for transporting cars and lorries, it serves both markets with the same frequency f. Also, the semi-fixed cost $C_F(f)$ cannot be separated between cars and lorries. The medium-term profits of the ferry are the sum of total revenues from both markets minus marginal cost in both markets minus semi-fixed cost. When the ferry exits, it exits both markets. It will stay in operation if the joint net revenues from car and lorry markets cover semi-fixed cost.

5.3 Results

Previous studies (Femern A/S, 2014; Incentive, 2015; Intraplan/BVU, 2014) presume that the Fixed Link will charge a price of 65 Euro per car and 267 Euro per lorry.[9] These prices do not result from any explicit optimization but are based upon historical ferry list prices. As a baseline scenario, DIW Econ (2015c) considers these tunnel prices as fixed and examines the ferry's long-term best response. It finds that the ferry will undercut the tunnel tolls by roughly one half (31 Euro/car, 141 Euro/lorry) and will take a market share of 37 percent in the car market and 80 percent in the lorry market. This will secure the ferry a decent profit, so that the ferry will stay in the market.

To study the ex-ante profitability of the tunnel, DIW Econ (ibid.) calculates the present value (PV) of the tunnel's expected revenue over a 50 year period after opening. It subtracts the cost (PV) of building and maintaining the tunnel. The report finds that in the baseline scenario the tunnel incurs a loss of at least 3 billion Euro (PV) over the 50 years due to the large market shares captured by the ferry.

After the baseline analysis, DIW Econ (ibid.) examines the Stackelberg model (skipped here) and then Bertrand equilibria. If tunnel and ferry set prices simultaneously, results vary substantially with assumptions on demand elasticity. The scenario with higher elasticity implies quite strong demand reaction, which is why the inelastic case seems more realistic. But there is no specific empirical evidence to support this assessment. Results are as follows. If demand is inelastic, the ferry will generate a small positive profit and should be able to stay in the market in the long run. The tunnel then runs a loss exceeding 1.8 billion Euro (PV), again calculated for a 50 year period after opening. If demand is more elastic, the ferry incurs losses in the medium-term equilibrium. Hence, in the long run the ferry will exit the market and the tunnel will be able to enjoy monopoly profit. In this scenario, the tunnel is ex-ante profitable; its revenues (PV) exceed the cost (PV) of building and maintaining the tunnel.

Notice that all results depends on many estimated variables and must rely on a set of assumptions. They also presume that the basic traffic forecast results of Intraplan/BVU (2014) remain valid.

[9] Femern A/S (2014) includes a discount for lorries.

6 Conclusion

This note models an asymmetric duopoly. The two competitors offer essentially the same service (passage over the Great Belt) but differ in type and quality (average crossing time) of their specific service as well as their cost structure. One competitor (the tunnel) varies its price, maximises revenue and offers a fixed quality (crossing time). The other one (the ferry) can change both its price and its schedule, resulting in varying quality levels (average crossing time). In the long run, the ferry can also exit the market.

The design of the model is deliberately simple and tailored to address two questions: 1. Will the tunnel induce the ferry to exit the market, once it operates? 2. Will the tunnel's toll revenues suffice to cover its cost? The note provides the model-theoretic conditions to answer these question.

In a related report, DIW Econ (2015c) calibrates the model with real-world data. The application challenges previous findings concerning the commercial viability of the Fixed Link (Femern A/S, 2014; Incentive, 2015; Intraplan/BVU, 2014). Specifically, the results of DIW Econ (2015c) indicate that the ferry is a much stronger competitor to the planned Fixed Link than previously suggested, and that one should not take it for granted that the ferry will exit the market. In fact, it seems more likely that the ferry will make positive profits in equilibrium and stay in the market. This is quite a challenge for the Fixed Link, because the results also suggest that as long a the ferry competes, the tunnel will not be a profitable business.

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