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The Static-Dynamic Efficiency Trade-off in the US Rail Freight Industry: Assessment of an Open Access Policy[a]

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ABSTRACT

Considering the US railroad industry, which is characterized by seven integrated firms that provide freight services on tracks they own and maintain, this paper provides a structural model that allows to evaluate the potential effects of opening the rail network to new firms on prices and investment incentives. In particular, we propose a framework for analyzing the tension between static efficiency (pricing behavior) and dynamic efficiency (investment behavior). The investment behavior is rendered endogenous by means of a dynamic model where the current investment depends on the expected future profits. We then use a forward simulation procedure to analyze the effect of an open-access market structure where a new firm uses the network of one of the biggest railroad firm. Under a simple access charge equaled to the marginal cost of access, investment in network infrastructure decreases by 10% per year, leading to a significant decrease in network quality over time. Under this setting, despite the increase of price competition, the decrease in network quality leads to a fall in consumer welfare. Other types of (more evolved) access charges might even allow to relax the tension between static efficiency and dynamic efficiency, allowing more price competition while preserving investment incentives. This topic deserves further research and is beyond the scope of this paper.

Keywords: competition, dynamic structural models, investment, open-access, railroad industry, static-dynamic efficiency trade-off
JEL Codes: C54, L10, L51, L92

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1 Introduction

The U.S. rail freight industry is organized into seven integrated firms which operate on tracks they own and maintain, and a fringe of hundreds of smaller railroads operating mostly in point-to-point markets. This concentrated structure is the result of waves of mergers and acquisitions.[1,2] Recently, a debate has started regarding the market power of the large railroad firms, and in particular their ability to foreclose competitive access to their tracks. In this context, an open-access market policy, where the incumbent is required to provide access to competitors over (portions of) its network facilities, has been put forward to foster competition.[3] An open-access market policy would enable competing railroads to reach shippers by using rivals' tracks and terminal facilities under regulated access fees. However, several arguments have been advanced against an open-access structure on the U.S. railroad network. While the market structure is different in Europe, similar issues are likely to arise with the fourth railway package adopted in 2016.[4]

One argument is linked to potential cost-inefficiencies due to entry. Berndt *et al.* (1993a, 1993b) and Ivaldi and McCullough (2001, 2008) analyze the railroad cost technology and find important operational economies of density. In this case, division of traffic among operators on a single network might lead to a loss of freight volume for the incumbent and an increase in the marginal costs of providing freight services.

This paper deals with a second argument, which is that opening the rail network to competition might decrease incentives to invest in the network. Track infrastructure is the result of previous and continuing costly investment by incumbent firms and it is the main driver of the quality of services in

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[1] Namely, these seven companies are: Burlington Northern and Santa Fe Railway Company (BNSF), Kansas City Southern Railway Company (KCS), Union Pacific Railroad (UP), Soo Line Railroad Company (SOO) which represents the U.S. operations of the "Canadian Pacific" railways company, CSX Transportation Inc. (CSX), Norfolk Southern Combined Railroad Subsidiaries (NS), Grand Trunk Corporation (GTC) which represents the U.S. operations of the "Canadian National" railways company. Source: Surface Transportation Board (STB).
[2] See Waters (2007) and Wilner (1997) for a history of Mergers and Acquisitions in the U.S. railroad industry. See also Gallamore and Meyer (2014).
[3] See for instance the report from the Government Accountability Office published in 2008.
[4] The 4th Railway Package is a set of six legislative texts designed to complete the single market for Rail services (Single European Railway Area, see https://ec.europa.eu/transport/modes/rail/packages/2013_en for further details). In particular, the 'Governance Directive' deals with the opening of the market of domestic passenger transport services by rail and the governance of the railway infrastructure (Directive 2016/2370/EU).

the rail industry. Obliging the incumbent to share its facilities with rivals would be an infringement of its property rights and could enable the entrant to benefit from good network infrastructure without bearing the cost of investment. The entrant would free-ride on the investment in network infrastructure and the prospect of expropriation would discourage the incumbent from upgrading the network in the future. The issue of investment incentives is particularly important in the railroad industry since it could have severe consequences for the quality/capacity/reliability of the network, and hence for the economic performance of the industry. This problem of investment expropriation (also called *hold-up* in the economic literature) is also mentioned for example in Motta (2004, Chapter 2), several OECD reports (1997, 2006), and in the Christensen (2008) study of the U.S. rail system.

In this paper, opening the network to competition affects investment behavior in two ways. First, to sustain innovation, and thus to support dynamic efficiency, investment requires a rate of return which can be obtained through above-marginal cost pricing over time and this leads to a degree of allocative inefficiency. Some prospects of profits are necessary to motivate firms to make costly investment. Otherwise, a firm would not be able to recoup its fixed cost of investment. Thus, an open-access market structure, which may decrease anticipated rates and revenues, could lead to a cut in investment. In other words, if railroads do not earn a fair market return, then they reduce investment. Second, sharing a network might lead to less rail freight volume for the incumbent.[5] Indeed, the smaller the proportion of train traffic operated by the owner of the infrastructure, the weaker the incentives to carry out such investment as the benefits of investment are shared by other independent train operating companies.

Taking into account these aspects, the contribution of this paper is to provide an empirical framework for analyzing the tension between pricing behavior that is revised each period affecting the short-term efficiency (*static efficiency*) and investment behavior that impacts long term efficiency (*dynamic efficiency*), in the context of an open-access policy. In particular, this paper presents a structural econometric analysis of the potential effect that opening an individual railroad's network to new firms would have on incentives to invest in network infrastructures, under a regulated access price.

[5] For example, some customers can shift from the incumbent to the entrant. Moreover, when several railroads are active on the same network, it reduces the number of slots available due to the necessary coordination of train operations to account for safety and technical constraints.

We consider investment as a dynamic behavior. Indeed, current investment is a determinant of the quality of the network tomorrow, and it depends on the expected returns from the network. If the firm anticipates high returns from its network, it will have an incentive to increase its investment today. In the model, this dynamic behavior is captured by a choice of investment such that the current marginal cost of investment is equal to the expected marginal benefit of investment in the future. Thus, obliging a firm to share its network might lead to a decrease in its current investment if the expected future benefits decrease too much due to increased competition.

The econometric model includes two elements. The first element is the estimation of a demand model, where the issue of attrition due to the concentration in the US railroad industry over time is fully addressed using the methodology developed by Coublucq (2013). This estimated demand model is later used to simulate the expected future profits with an open-access market structure. The second element is a model of the endogenous decision to invest in the network. The cost of investment is estimated in order to rationalize the observed investment as the equilibrium of the model. In the final step, the demand and the investment models are used in simulations to find the new equilibrium prices and investment with an open-access market structure. Since investment depends on the anticipated future mark-ups, we use a forward-simulation procedure. (See Judd, 1998.)

Using the estimated parameters and the corresponding demand and investment models, we simuaate a simple open-access policy where a new entrant pays a marginal cost access fees to provide freight services on the network of one of the biggest railroad firm. We find that this simple open-access policy decreases the average price in the industry by 6%. At the same time, the investment of the incumbent firm decreases by 10% per year, leading to a significant decrease in the quality of the network over time. Overall, the welfare of the shippers that use the network decreases. These findings are robust to different specifications of the simulations. (See Appendix 3.)

The framework of this paper also allows to consider other types of (more evolved) access charges, which might even allow to relax the tension between static efficiency and dynamic efficiency, allowing more price competition while preserving investment incentives. This topic on the optimal design of access charge deserves further research and is beyond the scope of this paper.

The reminder of the paper is organized as follows: Section 2 describes the US rail freight industry and the data; Section 3 presents the theoretical framework, with the trade-off between the static efficiency and the dynamic efficiency; Section 4 presents the structural analysis, which includes the demand and the investment models, with the estimation results; Section 5 presents the simulation of an open-access policy; Section 6 concludes.

2 Industry background

2.1 Overview of the US railroad industry

The US railroad industry is composed of short line, regional and Class 1 railroads. Our dataset covers only the Class 1 railroads (i.e., having operating revenue in excess of 346.8 milion US dollars in 2006), which account for 67% of industry's mileage, 90% of its employees and 93% of its freight revenue. Figure 1 illustrates the network configuration of the industry. The structure of the US rail freight industry is characterized by the integration of the network and the provision of freight services. In other words, the US freight railroads operate on tracks they own and maintain.

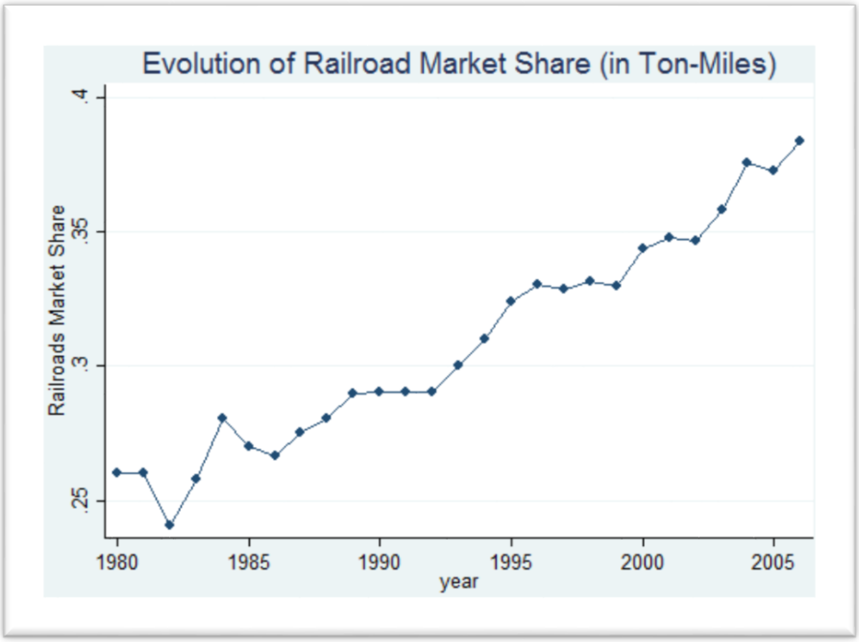
Figure 1. Network configuration of the US rail freight railroads in 2009

(Source: http://www.cn.ca/en/cn-and-class-1-railroads-flash.htm)

The U.S. rail industry is also characterized by a rather "light" regulation. This regulatory freedom came from the Staggers Act which deregulated US railroads in 1980. The Staggers Act gave the railroads the ability to adjust their rates and capital structures fairly easily and to enter into contracts with shippers. This deregulation process was accompanied by several takeover waves and this led to today's concentrated industry. There were 26 firms in 1980 and there are only seven firms today. (See Appendix 1 for further details.)

All railroads (Class 1s, short lines and regional railroads) accounted for 41% of freight ton-miles in 2007, more than any other mode of transportation. Figure 2 illustrates the increasing importance of Class 1 railroads in the US national freight market, where the market share (on a ton-mile basis) of the Class 1 US railroad firms has increased from 27% in 1980 to 38% in 2006. The total US national freight market is comprised of carriers by air, truck, railroad, water, and pipeline.

Figure 2. Evolution of the Class 1 railroads market shares in the US national freight market



2.2 Dataset and description of key variables

The main source of data is the *Analysis of Class1 Railroads* (hereafter *Analysis*) published annually by the Association of American Railroads (AAR). The *Analysis* is based on regulatory reports that railroads submit to the Surface Transportation Board (STB). In order to adjust for the effect of inflation, we convert the monetary variables in current dollars ($1982) using the Consumer Price Index from the *Statistical Abstract of the US* (see also the US Bureau of Labor Statistics). Table 1 presents some descriptive statistics.

Table 1. Descriptive statistics on US Class1 railroad data (key variables: prices, capital stock, and investment[6])

Variable	Unit	Obs	Mean	Std. Dev.	Min	Max
Price	\$1982	353	.0260265	.0114441	.0103483	.0853767
Capital stock $K_{j,t}$	\$1982 (000)	353	3289.989	2842.068	141.6636	11715.29
$k_{j,t} = \ln(K_{j,t})$	\$1982	353	7.604252	1.111563	4.953455	9.368649
Investment	\$1982 (000)	353	148.6064	422.8632	-2204.974	4223.662

Price data. Regarding the construction of the price of providing freight services, we build the series in the ton-miles unit. In particular, for each firm j active in year t, the *Analysis* gives the *Total Gross Freight Revenue* (line 599) and the *Total Ton-Miles* (line 711). We compute the price of freight in ton-miles using the formula:

$$p_{j,t} = \frac{Total\ gross\ freight\ revenue\ of\ firm\ j\ at\ year\ t}{Total\ ton\text{-}miles\ of\ firm\ j\ at\ year\ t}.$$

This allows us to build price series that are consistent with the study of the Surface Transportation Board (STB), *Study of Railroad Rates: 1985-2007* (2009), using the data from the *Analysis*. In fact, the STB has access to confidential and very detailed data (in particular the *Official Waybill Sample* that records the prices of the commodities shipped in the US), whereas we have access to the *Analysis* where pricing information is not directly available. For a particular year t, the industry price index is computed by a weighted average of the prices $p_{j,t}$ of active firms, where the weights are equal to the market share of firm j at year t:

$$s_{j,t|g=1} = \frac{Total\ ton\text{-}miles\ of\ firm\ j\ at\ year\ t}{Total\ industry\ ton\text{-}miles\ at\ year\ t}.$$

We compute a price index where the *Total Gross Freight Revenue* in current dollars is expressed in real \$1982 using the Consumer Price Index as a deflator. (See the Statistical Abstract of the US.) In Figure 3 and Figure 4, we show that the evolution of the price index is consistent with the evolution of the price index built by the Surface Transportation Board. Thus, using ton-miles allows us to consistently

[6] At the beginning of the 1980s, some railroad firms have abandoned some unprofitable lines and disinvested. Our theoretical framework can accommodate negative investment as well.

reproduce the evolution of railroad rates reported by the Surface Transportation Board. Using ton-miles also allows to use data from the US Department of Transport to estimate the total size of the freight market in the US, which is used to construct the market share of each railroad firm (and the market share of the outside alternative).

Figure 3. Industry price index (unit of measure: ton-miles, in real $1982, 1980 = 100)

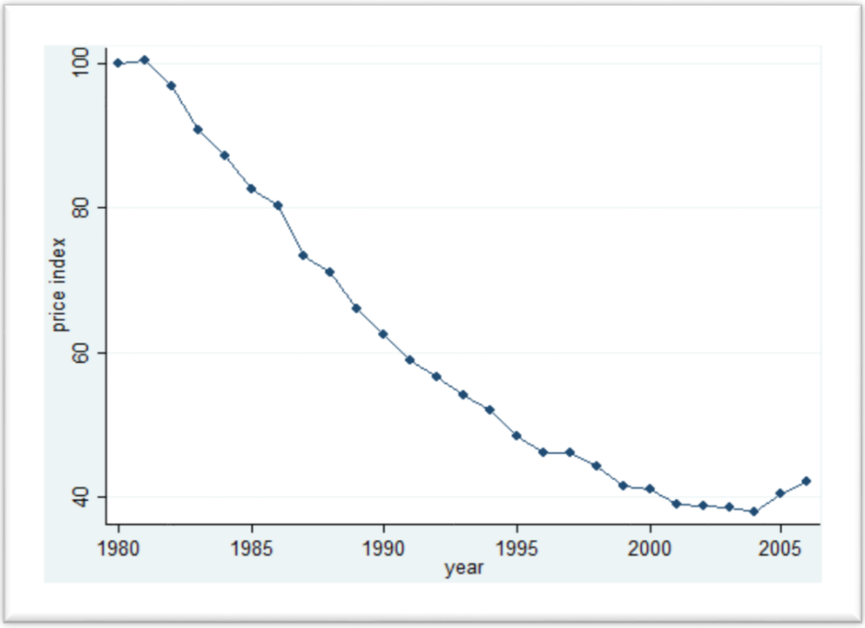
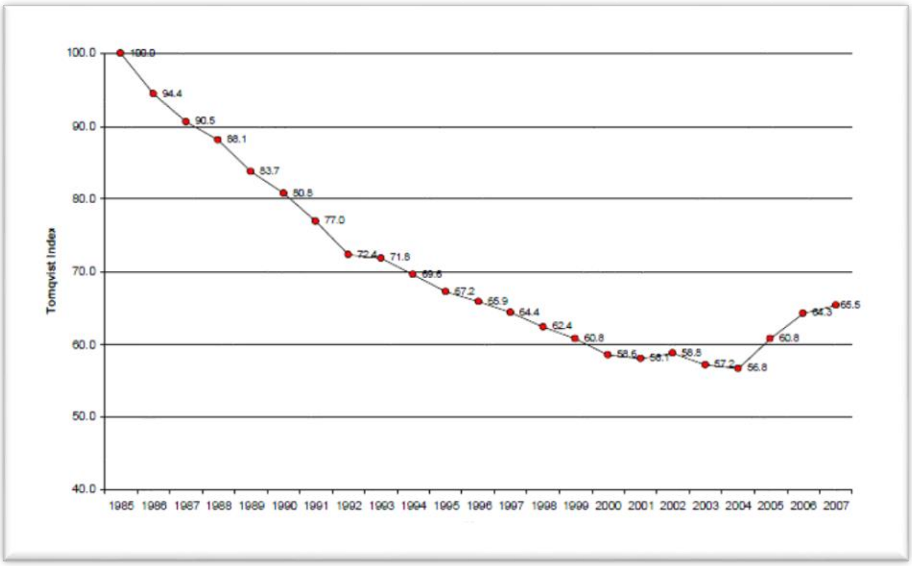


Figure 4. Rail rate index (1985 to 2007): Real revenue per ton-miles (1985 = 100)



Capital and investment in the network. In this paper, we focus on the investment in network infrastructures. We take the definition of the Schedule 350 of the regulatory R1 Reports published by the Surface Transportation Board. This definition includes investment in tunnels, bridges, ties, tracks and rail materials, ballasts, fences, and signalling materials for instance.

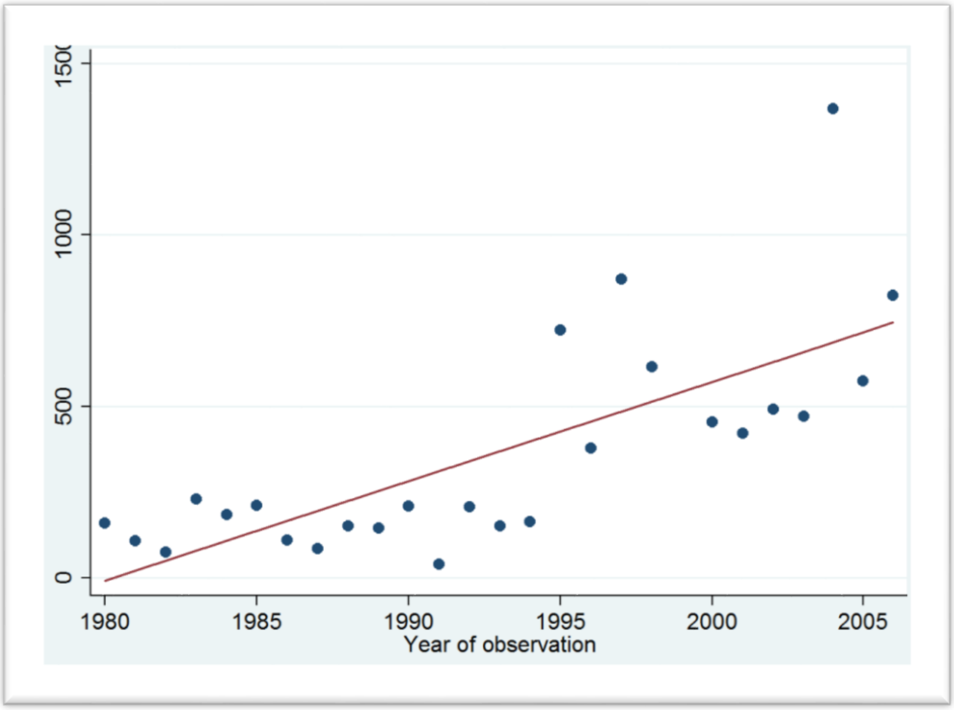
The construction of the capital stock follows the methodology of Berndt, Friedlaender, and McCullough (1992). Accordingly, we start from an authoritative estimate of the reproduction cost of capital in 1973 using Nelson (1975) and update the stock of capital of firm j using the perpetual inventory relation:

$$K_{j,t+1} = K_{j,t}(1-d) + I_{j,t}, \tag{1}$$

where $I_{j,t}$ represents the real investment (in \$1982) at year t. The depreciation rate d is derived by solving an equation that allows railroad capital to depreciate exponentially over 25 years to a salvage value of 10 percent.[7] The *Analysis* reports nominal investment which is then converted into real value (\$1982). The main difficulty lies in measuring this nominal investment component for way and structures capital. Before 1982, railroads used "betterment" accounting in which the work on railroad way and structures was listed as an expense and thus excluded from the undepreciated book value of road (line 67 in the *Analysis*). Thus, a first difference of the undepreciated book value of road allows measuring the nominal investment at every year. After 1982, the railroad industry adopted a depreciation accounting system, where the work on way and structures is added to the book value of road. It is thus necessary to remove the expenditures linked to the maintenance of the network (line 174 minus line 172 in the *Analysis*) from the undepreciated book value of road and then do a first difference to obtain the nominal investment. This perpetual inventory process is iterated to bring the series of way and structure capital until 2006. Figure 5 shows the evolution of investment over time.[8]

[7] The 25-years assumption is based on Berndt et al. (1992).
[8] For each year, Figure 5 shows a weighted average of the investment of the active firms, weighted by their market shares.

Figure 5. Evolution of investment (in thousands, real $1982)



3 Theoretical background

The objective of this paper is to provide an empirical framework to analyze the tension between static efficiency (pricing behavior) and dynamic efficiency (investment behavior) in the US rail freight industry, in the context of an open-access policy. This paper relies on a two-stage equilibrium model, with a choice of price at each period and a choice of quality over time through the investment decision.[9]

3.1 Pricing behavior and demand function

We consider a model of differentiated products where firms engage in Bertrand competition in prices. (See Berry, 1994.) This allows defining the demand function of the consumers, i.e., the shippers in the US rail freight industry. The demand function allows us to define the market share and the profit function that determine the pricing behavior of the railroad firms.

[9] There is a third decision which is an exit decision. However, this paper focuses on the investment decision. The exit decision is useful to deal with the selection issue due to mergers. (See Appendix 1.) (See also Coublucq, 2013, for further details.)

Following Berry (1994), we group the firms into two groups and exclusive sets, $g = 0,\ 1$, where $g = 0$ denotes the outside option, which is the freight provided by air, truck, water, and pipeline, and $g = 1$ denotes the group containing the railroad firms. The utility of a shipper i from choosing the railroad firm j is:

$$u_{i,j,t} = \delta_{j,t} + \zeta_{g,t} + (1-\sigma_g)\varepsilon_{i,j,t}, \tag{2}$$

where $\delta_{j,t}$ is the mean-utility of choosing railroad j at time t and $\varepsilon_{i,j,t}$ is identically and independently distributed with the extreme value distribution. The variable $\zeta_{g,t}$ is common to all firms in group g and follows a Cardell (1997) distribution $C(\sigma)$, with $\sigma \in (0;1)$. The parameter σ represents the within group correlation of all the alternatives in the group $g = 1$.

In the expression of the mean-utility, $\delta_{j,t} = \theta k_{j,t} - \alpha p_{j,t} + \xi_{j,t}$, $k_{j,t} = \ln(K_{j,t})$ represents the impact of network quality on the utility of shippers, $p_{j,t}$ is the price of using the railroad firm j to provide the freight service, and $\xi_{j,t}$ represents the unobservable efficiency of railroad firm j at time *t*. The capital stock is updated at each time period using the relation $K_{j,t} = K_{j,t-1}(1-d) + I_{j,t-1}$, where $I_{j,t-1}$ stands for investment in the network infrastructure.

The market share formula for this nested logit model is:

$$s_{j,t}(\boldsymbol{\delta},\ \sigma) = s_{j,t|g}(\boldsymbol{\delta},\ \sigma)s_{g,t}(\boldsymbol{\delta},\ \sigma) = \frac{\exp\left(\frac{\delta_{j,t}}{1-\sigma}\right)}{D_{g,t}^{\sigma}\left[\sum_g D_{g,t}^{1-\sigma}\right]}, \tag{3}$$

where $s_{j,t|g}(.)$ denotes the within market share of firm j at time t in the group $g = 1$, $\boldsymbol{\delta}$ denotes the vector of mean-utilities of all railroad firms, σ denotes the within group correlation of railroad firms, and $D_{g,t} \equiv \sum_{j \in g} \exp(\delta_{j,t}/(1-\sigma))$. The market share of the outside alternative is given by $s_{0,t}(\boldsymbol{\delta}, \sigma) = 1 \big/ \sum_g D_{g,t}^{1-\sigma}$.

From Equation (3), we see that the market share, denoted by $s_{j,t}(.)$, is a function of the characteristics of the industry, denoted by $\boldsymbol{w}_t = (K_{1,t},\ldots,K_{j,t},\ldots,K_{J_t,t};\xi_{1,t},\ldots,\xi_{j,t},\ldots,\xi_{J_t,t})$, and the prices of the railroads firms, denoted by the vector $p_t = (p_{1,t}, \dots, p_{J_t,t})$, where J_t denotes the number of active firms at date t.

Thus, we can define the profit function that determines the pricing behavior as:

$$\pi_{j,t}(\boldsymbol{w}_t, \boldsymbol{p}_t) = (p_{j,t} - mc_{j,t}) s_{j,t}(\boldsymbol{p}_t, \boldsymbol{w}_t) M_t, \tag{4}$$

where $p_{j,t}$ is the price charged by firm j, $s_{j,t}$ is the market share of firm j, M_t represents the size of the freight market at date t, and $mc_{j,t}$ is the cost of providing freight services on its own network.

Using Equation (4), the first-order condition for pricing behavior of firm j, $j = 1, \dots, J_t$ is:

$$(p_{j,t} - mc_{j,t}) \frac{\partial s_{j,t}}{\partial p_{j,t}} + s_{j,t} = 0, \tag{5}$$

From Equation (5), we show that the price equilibrium vector for all the active firms is a function of the state variables, denoted by $\boldsymbol{w}_t$, that is $\boldsymbol{p}_t(\boldsymbol{w}_t)$, which allows to define the profit function (4) as $\pi_{j,t}(\boldsymbol{w}_t) \equiv \pi_{j,t}(\boldsymbol{w}_t, p_t(\boldsymbol{w}_t))$.

3.2 Investment behavior

The pricing decision above is static and impacts the spot profit function, denoted $\pi_{j,t}(\boldsymbol{w}_t)$. In contrast, investment is a dynamic decision and it depends on the anticipated future benefit. In addition to receiving profits, an active firm incurs a cost of investment, $c(I_{j,t})$.

We define the value function of firm j at date t as:

$$V_{j,t}(\boldsymbol{w}_t) = \sup_{i_{j,t}(\boldsymbol{w}_t)} \pi_{j,t}(\boldsymbol{w}_t) - c(I_{j,t}(\boldsymbol{w}_t)) + \mu E\left\{V_{j,t+1}(\boldsymbol{w}_{t+1} \mid \boldsymbol{w}_t)\right\}, \tag{6}$$

where μ is the discount rate, conditions at time t are summarized by a vector of state variables with $\boldsymbol{w}_t = (K_{1,t}, \dots, K_{j,t}, \dots, K_{J_t,t}; \xi_{1,t}, \dots, \xi_{j,t}, \dots, \xi_{J_t,t})$, and $E\left\{V_{j,t+1}(\boldsymbol{w}_{t+1} \mid \boldsymbol{w}_t)\right\}$ represents the anticipated future benefit.

In Equation (6), the function $c(I_{j,t})$ should be interpreted as an adjustment cost function. This is because it takes one period for new capital to be installed by firms, and, at date $t-1$, the firm must bear the cost of adjusting the capital stock, denoted $c(I_{j,t-1})$.[10]

Using Equation (6), the first-order condition that determines the investment behavior of the firm is:

$$-\frac{\partial c(I_{j,t})}{\partial I_{j,t}} + \mu E\left[\frac{\partial V_{j,t+1}(w_{t+1} \mid w_t)}{\partial I_{j,t}}\right] = 0. \tag{7}$$

This first-order condition can be rewritten as:

$$\frac{\partial c(I_{j,t})}{\partial I_{j,t}} = \mu E\left[\frac{\partial V_{j,t+1}(K_{j,t+1}, \boldsymbol{K}_{-j,t+1}, \xi_{j,t+1}, \boldsymbol{\xi}_{-j,t+1} \mid w_t)}{\partial K_{j,t+1}}\right], \tag{8}$$

since the perpetual inventory method that we use to construct the stock of capital, $K_{j,t+1} = K_{j,t}(1-d) + I_{j,t}$, implies that $\partial K_{j,t+1} / \partial I_{j,t} = 1$. Equations (7) and (8) captures the idea that the level of investment is such that the marginal cost of investment is equal to the anticipated marginal benefit of investing in the network. This captures the idea that investment is a dynamic activity.

Using the envelop theorem, we can write:

$$\begin{aligned}\frac{\partial V_{j,t}(K_{j,t}, \boldsymbol{K}_{-j,t}, \xi_{j,t}, \boldsymbol{\xi}_{-j,t}, J_t)}{\partial K_{j,t}} &= \frac{\partial \pi_{j,t}(K_{j,t}, \boldsymbol{K}_{-j,t}, \xi_{j,t}, \boldsymbol{\xi}_{-j,t}, J_t)}{\partial K_{j,t}} \\ &\quad + \mu(1-d)\frac{E[\partial V_{j,t+1}(K_{j,t+1}, \boldsymbol{K}_{-j,t+1}, \xi_{j,t+1}, \boldsymbol{\xi}_{-j,t+1}, J_{t+1})]}{\partial K_{j,t+1}}.\end{aligned} \tag{9}$$

Combining Equations (8) and (9), we obtain:

$$\begin{aligned}&\frac{\partial c(I_{j,t})}{\partial I_{j,t}} = \mu E\left[\frac{\partial V_{j,t+1}}{\partial K_{j,t+1}}\right] \\ &\Rightarrow \frac{\partial c(I_{j,t})}{\partial I_{j,t}} = \mu E\left(\frac{\partial \pi_{j,t+1}}{\partial K_{j,t+1}} + \mu(1-d)\frac{\partial \pi_{j,t+2}}{\partial K_{j,t+2}} + (\mu(1-d))^2\frac{\partial \pi_{j,t+3}}{\partial K_{j,t+3}} + \ldots\right) \\ &\Rightarrow \frac{\partial c(I_{j,t})}{\partial I_{j,t}} = \mu E\left(\sum_{\tau=1}^{T}(\mu(1-d))^{\tau-1}\frac{\partial \pi_{j,t+\tau}}{\partial K_{j,t+\tau}}\right),\end{aligned} \tag{10}$$

where

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[10] This assumes that capital is a fixed (rather than variable) input.

$$\frac{\partial \pi_{j,t+\tau}}{\partial K_{j,t+\tau}} = M_{t+\tau}(p_{j,t+\tau} - mc_{j,t+\tau})\frac{\partial s_{j,t+\tau}}{\partial K_{j,t+\tau}}. \tag{11}$$

Equations (10) and (11) capture the following idea. To sustain innovation, and thus to support dynamic efficiency, investment requires a rate of return which can be obtained through above-marginal cost pricing over time and this leads to a degree of allocative inefficiency. In other words, some prospects of profits are necessary to motivate firms to make costly investment. Otherwise, a firm would not be able to recoup its fixed cost of investment.

3.3 The static-dynamic efficiency trade-off: Comment

In the model, an open-access market structure, which creates more competition and a decrease in prices which improves the allocative efficiency and the consumer welfare at the current date (static efficiency), leads also to a decrease in the anticipated mark-ups in Equation (11), i.e., in the return on the investment, and this leads to a decrease in the incentives to invest in the network at date t in Equation (10). Over time the decrease in investment decreases the quality of the network, which has a negative impact on the consumer welfare (dynamic inefficiency). This is the trade-off between static efficiency and dynamic efficiency with an open-access policy, which is illustrated in the simulations in Section 5 with a simple access charge equaled to the marginal cost of provided access. The framework of this paper also allows to consider other types of (more evolved) access charges, which might even allow to relax the tension between static efficiency and dynamic efficiency (i.e. allowing more price competition while preserving investment incentives). This topic on the optimal design of access charge is beyond the scope of this paper.

A last remark should be added regarding the relation between the volume of traffic and the trade-off between static and dynamic efficiencies with an open-access policy. As mentioned in the introduction, sharing a network might lead to less rail freight volume for the incumbent, and the smaller the proportion of train traffic operated by the owner of the infrastructure, the weaker the incentives to carry out such investment as the benefits of investment are shared by other independent train operating companies. This second effect deserves more comments. In general, opening the network to competition does not necessarily lead to a decrease in the rail traffic of the incumbent. For example, if an open-access policy leads to an important decrease in prices, the overall increase in the rail traffic might be such that the incumbent carries more freight, and this would have a positive impact on revenue. We can show that this second effect is captured by the term $\partial s_{j,t+1} / \partial K_{j,t+1}$ in Equation (11). In that case, it would be the balance between the negative effect of lower price and the positive effect of more freight volume that would determine the overall impact on revenue and on the incentive to invest in the network.

4 The structural analysis and estimation results

4.1 Specification and estimation of the demand model

This section presents the estimation of the demand model presented in Equations (2) and (3). Following Berry (1994), for a particular railroad firm j at year t, the estimating equation for the demand model (2) is:

$$\ln s_{j,t} - \ln s_{0,t} = \theta k_{j,t} - \alpha p_{j,t} + \sigma \ln s_{j,t|g} + \xi_{j,t}. \tag{12}$$

The concentration of the US railroad industry through mergers and acquisitions leads to an attrition issue. Indeed, while there were 26 Class 1 firms in 1980, only seven firms remain in 2006. (See Appendix 1.) Thus we need to consider the following moment conditions $E(\xi_{j,t} \mid z_{j,t}, r_{j,t} = 1)$, where $z_{j,t}$ denotes the instruments and $r_{j,t} = 1$ if firm j is observed at date t. If the merged firms differ from the non-merged firms in ways that are difficult to quantify, then the following moment conditions would be different from zero, that is $E(\xi_{j,t} \mid z_{j,t}, r_{j,t} = 1) \neq 0$.[11] Following Coublucq (2013), we consider the error term $e_{j,t} = \xi_{j,t} - E(\xi_{j,t} \mid z_{j,t}, r_{j,t} = 1)$, which is equal to zero in expectation by construction. The estimating equation becomes:

$$\ln s_{j,t} - \ln s_{0,t} = \theta k_{j,t} - \alpha p_{j,t} + \sigma \ln s_{j,t|g} + E(\xi_{j,t} \mid z_{j,t}, r_{j,t} = 1) + e_{j,t}. \tag{13}$$

The methodology proposed by Coublucq (2013) uses a dynamic model of exit to endogenize attrition and compute the correction term for attrition, $E(\xi_{j,t} \mid z_{j,t}, r_{j,t} = 1)$. In his framework, the

[11] Coublucq (2013) provides an estimation algorithm to deal with endogenous attrition due to concentration in the US railroad industry. The economic intuition behind the selection issue is that the better management takes the control through mergers. Indeed, Coublucq (2013) shows that that the concentration of the US railroad industry has led to a reallocation of assets from less efficient to more efficient firms.

unobserved firm efficiency follows the process $\xi_{j,t} = c_j + \rho\phi_{j,t-1}$, where c_j represents firm fixed-effect and $\phi_{j,t-1}$ represents the exit value. Incorporating firm fixed-effect means that firms are selected out of the sample based on unobserved fixed heterogeneity. (See Wooldridge, 1995, and Semykina and Wooldridge, 2005.) Incorporating the exit value $\phi_{j,t-1}$ allows to control for endogenous attrition. (See Coublucq, 2012.) Moreover, there is a lag of one period between $\xi_{j,t}$ and $\phi_{j,t-1}$ since a firm is observed at date t if it has decided to stay active in the market the period before. The lag of one period implies that we need to condition on the past information set, denoted $\boldsymbol{w}_{t-1}$, to compute the correction term for attrition. (See Coublucq, 2013.)

Using the process of the unobserved firm efficiency in (13), we obtain the following estimating equation:

$$\ln s_{j,t} - \ln s_{o,t} = \theta k_{j,t} - \alpha p_{j,t} + \sigma \ln s_{j,t|g=1} + c_j + \rho\lambda_{j,t-1}(\boldsymbol{w}_{t-1}) + e_{j,t}, \tag{14}$$

where $\lambda_{j,t-1}(w_{t-1})$ denotes the correction term for attrition. We assume that the exit value follows an exponential distribution, denoted by $G(.)$. This implies that the firm gets a strictly positive scrap value when it decides to exit and sells its assets on a resale market. The correction term for attrition is then computed as:

$$\lambda(\boldsymbol{w}_{t-1}) \equiv 1 - \bar{\phi}_{i,t-1}\frac{\exp(-\bar{\phi}_{i,t-1})}{1-\exp(-\bar{\phi}_{i,t-1})}, \tag{15}$$

where $\bar{\phi}_{j,t-1} = G^{-1}(P_{j,t-1}(w_{t-1}))$ and $P_{j,t-1}(\boldsymbol{w}_{t-1})$ represents the probability that the firm j stays active in the market at date $t-1$. The threshold $\bar{\phi}_{j,t-1}$ means that the firm stays in the market if its scrap value $\phi_{j,t-1}$ is lower than the threshold $\bar{\phi}_{j,t-1}$. If the scrap value is higher than the threshold $\bar{\phi}_{j,t-1}$, then the firm exits the market and sells its assets through a resale market. (See Coublucq, 2013.)

Next, we eliminate the firm fixed-effect by a first-difference in (14), which leads to the following estimating equation:

$$\Delta y_{j,t} = \theta\Delta k_{j,t} - \alpha\Delta p_{j,t} + \sigma\Delta \ln s_{j,t|g=1} + \rho\Delta\lambda_{j,t-1} + \Delta e_{j,t}, \tag{16}$$

where Δ denotes the first-difference operator: $\Delta e_{j,t} = e_{j,t} - e_{j,t-1}$.

From this equation, we estimate the demand parameters (θ, α, σ) using a GMM procedure. The parameter ρ represents the importance of endogenous attrition. In the estimation, we include a *quadratic time trend* in order to capture disembodied technical change. As instruments, we use cost-shifter variables such as the *miles of road operated* (*ROAD*), *the average length of haul* (*HAUL*), the lag of these six variables, and the lag of the BLP instrument for *ROAD*.[12] The two variables *ROAD* and *HAUL* are used as instruments since they are considered as cost-shifters. (See Berndt *et al*., 1993a and 1993b, Ivaldi and McCullough, 2001, 2008.) Other instruments include the lag of capital stock, $K_{j,t-1}$, and the second lag of the correction term, $\lambda_{j,t-2}$. We have also added $K_{j,t-2}$ as an instrument. A discussion of the validity of the instruments and the estimation algorithm is in Appendix 2. (For further details, see Coublucq, 2013.)

Table 2 presents the estimation results for the demand parameters. All coefficients have the expected signs. The correction term is significant at the 5% level. This confirms that the methodology of Coublucq (2013) helps to deal with endogenous attrition due to concentration.[13] The Sargan test does not reject the over-identifying restriction, which therefore validates the choice of the instruments. The estimated demand model is then used later in Section 5 to simulate the future mark-ups with an open-access market structure.

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[12] Berry, Levinsohn, and Pakes (1995).

[13] Coublucq (2013) shows that the price and the capital stock coefficients are under-estimated when the issue of endogenous attrition is not taken into account.

Table 2. Demand estimates

Variable	Coefficient
Price (-α)	-67.468***
	(21.600)
Within correlation (σ)	.479
	(.388)
Correction term λ	.628**
	(.275)
$k_{j,t} = \ln(K_{j,t})$	.376
	(.256)
Time effect[14]	Yes
Number of observations	353
Sargan ($\chi^2(7)$)	6.129
	(p = 0.5250)

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

4.2 Marginal costs

Using the demand estimates, we recover the marginal costs for each firm at a particular year by assuming that the firms engage in Bertrand competition in prices. Using the first-order condition for pricing behavior in Equation (5), with the demand estimates from section 4.1, we obtain the mark-up with the following formula:

$$p_{j,t} - mc_{j,t} = \frac{1-\sigma}{\alpha(1-\sigma s_{j,t|g=1} - s_{j,t}(1-\sigma))}.$$

Then we recover the marginal costs from the estimates of mark-ups using the formula $mc_{j,t} = -(p_{j,t} - mc_{j,t}) + p_{j,t}$.

Table 3 reports descriptive statistics about the mark-ups and marginal costs. The recovered marginal costs are used later in Section 5 to solve for the new equilibrium prices under the open-access market structure.

Table 3. Descriptive statistics for mark-ups and marginal costs

	Obs	Mean	Std. Dev	Min	Max
Mark-ups ($1982)	353	.0081	.0005	.0077	.0102
Marginal costs ($1982)	353	.0179	.01170	.0003	.0776

4.3 The investment model

This section presents the estimation of the adjustment cost function of the dynamic model of investment (Section 3.2). In particular, the estimation of the adjustment cost function rationalizes the observed investment behavior as the equilibrium of the dynamic game.

[14] A quadratic time trend is used to control for time effect.

Equation (6) defines the value function of firm j at date t, with $\boldsymbol{w}_t = (K_{1,t},\ldots,K_{j,t},\ldots,K_{J_t,t};\xi_{1,t},\ldots,\xi_{j,t},\ldots,\xi_{J_t,t})$, where $K_{j,t}$ represents the observable value of the network and $\xi_{j,t}$ represents the unobservable quality (or efficiency) of freight services provided by firm j. We are able to recover the firm efficiency, $\xi_{j,t}$, $\forall(j,t)$, using the demand parameters $(\hat{\theta},\hat{\alpha},\hat{\sigma})$ in Equation (12).

The only dynamic parameter relates to the adjustment cost function, $c(I_{j,t}) = bI_{j;t}^2$. The parameter b represents the importance of the adjustment cost. For example, a parameter significantly different from zero means that the capital stock is costly to adjust. (See Section 3.2.)

We use the GMM-Euler equation framework of Hansen and Singleton (1982) to estimate the parameter b in the adjustment cost function. Combining the first-order condition (8) with the envelop theorem (9), we obtain an Euler equation that can be estimated in a standard GMM framework. We obtain the following estimating equation:

$$E_{|t}\left[\delta\frac{\partial \pi_{j,t+1}}{\partial K_{j,t+1}} + \delta(1-d)bI_{j,t+1} - bI_{j,t} \mid \boldsymbol{w}_t\right] = 0, \tag{17}$$

where $\boldsymbol{w}_t$ represents the information available at date t.

We need to choose the instruments to form a GMM estimator. In Equation (17), the operator E_t represents the expectation conditioned on agents' period t information set, $\boldsymbol{w}_t$. As in Hansen and Singleton (1982), we use the economic model to generate a family of orthogonality conditions which are used to construct a criterion function. Then we estimate the dynamic parameter b by GMM. Let $\boldsymbol{z}_{j,t}$ be a vector of variables that are in the agent's information set at date t. We form the following orthogonality conditions:

$$E\left[\boldsymbol{z}_{j,t}' h(I_{j,t}, I_{j,t+1}, \boldsymbol{K}_{t+1}, \xi_{t+1}; b)\right] = 0, \tag{18}$$

where $\boldsymbol{z}'_{j,t}$ is a q dimensional vector, $h(.) = \delta \frac{\partial \pi_{j,t+1}}{\partial K_{j,t+1}} + b\left[\delta(1-d)I_{j,t+1} - I_{j,t}\right]$ and E denotes the unconditional expectation operator. We construct the function $g(b) = \boldsymbol{z}'_{j,t} h_{j,t}(I_{j,t}, I_{j,t+1}, \boldsymbol{K}_{t+1}, \xi_{t+1}; b)$, and we minimize the quadratic form $Q(b)$ with respect to the parameter b:

$$Q(b) = g(b)'Wg(b), \tag{19}$$

where the weighting matrix is written as $W = (Z'Z)^{-1} = \sum_{j,t} (z_{j,t}' z_{j,t})^{-1}$ as for linear two-stage least squares. Variables that represent the information available at date t are natural candidates for instruments. These includes price, mark-up, the number of active firms, and the average length of HAUL.[15][16],

Table 4 reports the estimate for the parameter of the adjustment cost function. This parameter is significantly different from zero.[17] This means that capital stock adjustment is costly. The economic intuition is that it may take a full period for new capital to be ordered, delivered, and installed. This is consistent with the perpetual inventory method that we used to construct the capital stock, that is $K_{j,t} = K_{j,t-1}(1-d) + I_{j,t-1}$.

Table 4. Adjustment cost of investment

	Coefficient
Adjustment cost of investment (b)	1.970873 (1.2239)
Number of observations	291
Sargan test	$\chi^2(3) = 2.94461$ (p = 0.4002)

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The estimated cost of investment is used in the simulation of the investment with an open-access market structure. The cost of investment is an important parameter in the model since the equilibrium

[15] The mark-ups for each firm can be recovered using the demand estimates with the first-order condition for the pricing behavior. (See section 4.2.)
[16] The last variable, HAUL, is useful since it is an important cost-shifter, and it can be related to the profitability of the firms and thus to the investment behavior.
[17] The standard errors are computed by bootstrap. The adjustment cost of investment is almost significant at 10%. Since the dataset is rather small, we cannot expect a large efficiency in the parameter estimates.

level of investment is determined by equating the marginal cost of investment with the expected future benefit.

5 Simulating an open-access policy

We now use the estimated demand and supply side parameters to simulate an open-access policy and quantify the impacts on prices and investment of mandating access to a particular network. Without loss of generality, we assume that the network of the incumbent firm "Burlington Northern"(denoted firm j) is opened to an entrant (denoted firm n).[18,19] The market structure is the same for all the other firms. We assume that this new market structure begins in 2006. Then, the investment of firm j in its network in 2006 is determined by the expected future benefits from 2006 onward. Once we know the investment in the network in 2006, we compute the value of the network in 2007 through the perpetual inventory relation. (See Equation (1).) We repeat this procedure for 30 years, until 2036. This shows the evolution of investment over a 30-year horizon. For the following, we denote 2006 by t_0, 2007 by t_1, until 2036. We will compare the investment under two market structures: the current structure where each firm provides freight services on its own network, and this specific open-access market structure.

The characteristics of the entrant are summarized by its mean-utility, denoted δ_{n,t_0}. The entrant uses the network of firm j, denoted K_{j,t_0}. Thus we can write the mean-utility of the entrant as $\delta_{n,t_0} = \theta k_{j,t_0} - \alpha p_{n,t_0} + \xi_{n,t_0}$, where $k_{j,t_0} = \ln(K_{j,t_0})$, p_{n,t_0} denotes the prices charged by the entrant to provide freight services, and ξ_{n,t_0} represents the intrinsic characteristics of the entrant. We assume that ξ_{n,t_0} is equal to the average efficiency of other active firms in 2006, that is $\xi_{n,t_0} = (1/J_{2006})\sum_{k=1}^{J_{2006}} \hat{\xi}_{k,2006}$, where $J_{2006} = 7$, since only seven firms are active in 2006. For the

[18] The biggest railroad firm is "Burlington Northern", which represents 36% of the freight services provided by the US Class 1 railroad firms in 2006.

[19] The model allows to open to entrants the networks of several incumbents. However, for the sake of clarity, in the simulations presented, it is enough to simulate the opening of only one network to illustrate the potential effects of an open-access policy on prices and investment.

simulations, we keep this variable fixed over time from 2006 onward. We also keep $\hat{\xi}_{k,t}$ fixed over time at their 2006 values for other firms, $\forall(k,t)$.

We consider the profit of an entrant at a particular date t, $t \geq t_0$, $\pi_{n,t} = (p_{n,t} - a)s_{n,t}(\boldsymbol{p_t})M_t$, where $p_{n,t}$ is the price charged by firm n, $s_{n,t}$ is the market share of the entrant, M_t represents the size of the freight market, and a is the cost of providing freight services on the network of the incumbent j. This cost, denoted by a, includes the (regulated) level of the access charge that the entrant pays to have access to the network of firm j, and its own cost of labor, energy, and material for instance. The price charged by the firm n is determined by the first-order condition:

$$(p_{n,t} - a)\frac{\partial s_{n,t}}{\partial p_{n,t}} + s_{n,t} = 0, \tag{20}$$

We need to know the cost, denoted by a, to derive the optimal price of the entrant n. We assume that it is equal to the marginal cost of the incumbent j in 2006, denoted as $mc_{j,2006}$.[20] (See Table 3.) Using the first-order conditions (5) and (20) for prices, we determine the equilibrium prices for the eight active firms.[21] These equilibrium prices depend on the marginal costs, the access charge, the size of the freight market, the intrinsic efficiencies ξ, and the levels of the capital stocks K for all active firms. Since we focus on the impact of open-access on the investment of the firm j, we consider the evolution of the capital stock of firm j, denoted $K_{j,t}$, and we keep everything else constant at their 2006 values. For example, from 2006 onward, the market size is set to its 2006 value and the marginal costs for each firm are also constant at their 2006 values. This allows us to isolate the impact of an open-access policy

[20] We need an assumption about the level of cost for the entrant. We assume that it is equal to the marginal cost of the incumbent. In this way, the entrant is as efficient as the incumbent in terms of cost. If we assume a more efficient entrant in terms of cost, then price competition becomes tougher, as well as the impact on investment disincentives.

[21] Regarding the profit of the incumbent, we assume that the access charge is equal to the marginal cost of providing access. Then the profit from access is zero for the firm j. This is coherent with the assumption that the cost of entry for the entrant is equal to $mc_{j,t}$. Indeed, from section 3.1, $mc_{j,t}$ represents the whole cost of providing freight on the network of firm j, which includes the part related to the network, denoted by $s\% \times mc_{j,t}$, and the part related to the cost of labor and materials, denoted by $(1 - s\%) \times mc_{j,t}$. Thus, under our assumption, the level of access charge is equal to $s\% \times mc_{j,t}$. Then the cost of entry for the new firm is equal to the level of the access charge, that is $s\% \times mc_{j,t}$, plus the cost of material and labor due to the provision of freight on the network of firm j, that is $(1 - s\%) \times mc_{j,t}$. This implies that the cost of entry is equal to $mc_{j,t}$.

on the investment of the railroad firm j. In Appendix 3, we check the robustness of the results by allowing the capital stocks of competitors to increase over time as well.

The equilibrium investment of the firm j is characterized by the first-order condition (10). Since we keep the intrinsic characteristics of every firm constant at the 2006 values, and the perpetual inventory relation for the capital stock is deterministic, there is no more uncertainty about the future. We can remove the expectation operator and write the first-order condition for $t \geq t_0$ as:

$$\begin{aligned} i_{j,t} &= \frac{\delta}{\hat{b}} \frac{\partial V_{j,t+1}}{\partial K_{j,t+1}} \\ \Rightarrow i_{j,t} &= \frac{\mu}{\hat{b}} \left(\frac{\partial \pi_{j,t+1}}{\partial K_{j,t+1}} + \mu(1-d) \frac{\partial \pi_{j,t+2}}{\partial K_{j,t+2}} + (\mu(1-d))^2 \frac{\partial \pi_{j,t+3}}{\partial K_{j,t+3}} + \ldots \right) \\ \Rightarrow i_{j,t} &= \frac{\mu}{\hat{b}} \left(\sum_{\tau=1}^{T} (\mu(1-d))^{\tau-1} \frac{\partial \pi_{j,t+\tau}}{\partial K_{j,t+\tau}} \right), \end{aligned} \tag{21}$$

where $\hat{b}$ is the estimated cost of investment and T represents the number of periods in the forward-simulation procedure. We assume that $T = 25$ periods. The 25-year assumption is based on Berndt, Friedlaender, and McCullough (1992).[22]

From Equation (21), we can write the derivative of the profit with respect to the capital stock $t \geq t_0$ as:[23]

$$\frac{\partial \pi_{j,t+1}}{\partial K_{j,t+1}} = M(p_{j,t+1} - mc_j) \frac{\partial s_{j,t+1}}{\partial K_{j,t+1}}, \tag{22}$$

where the market size M and the marginal cost mc_j are fixed at their 2006 values. This particular open-access policy creates more competition and thus a decrease in prices. This leads to a decrease in future mark-ups and a decrease in the incentives to invest in the network at date t in Equation (21).[24]

[22] As mentioned in Berndt, Friedlaender, and McCullough (1992), economic depreciation is derived by solving an equation that allows railroad equipment to depreciate exponentially over 25 years to a salvage value of 10 per cent.
[23] We assumed the access charge is equal to the marginal cost of providing access, then the profit from access is null for the firm j. In this way, we only focus on the expropriation issue mentioned in the introduction and its impact on the investment in network infrastructures. If the access charge is higher than the cost of providing access, then the profit function should include the profit from providing access. Thus, the first-order conditions for prices and investment of firm j will be different (see the conclusion about this issue).
[24] If the prices decrease due to competition leads to an important increase in the volume of freight, then the market is more attractive and the firm invests more on the network. This is captured by the term $\partial s_{j,t+1}/\partial K_{j,t+1}$.

To find the optimal investment at date t_0 , we use the following algorithm. (See Judd, 1998, for additional details.) We need to specify the shape of an investment policy function. This is necessary in order to forward-simulate the capital stock of firm j (the future capital stocks of firm j depends on its future investments, and thus on the future investment policy function). We specify the investment policy function as: $I_{j,t} = \gamma K_{j,t}$, where $\gamma \geq 0$. The algorithm finds the parameter γ such that the investment policy function is compatible with the first-order condition for the investment in Equation (21). Then we can compute the investment in 2006 using the investment policy function. For a given value of γ in the investment policy function, the algorithm is as follows:

1) Using the capital stocks at date t_0 , we compute the investment of firm j at date t_0 ;
2) We compute the capital firm of firm j at date t_1, using the perpetual inventory relation (1);
3) We solve for the optimal prices at date t_1 using the first-order conditions for prices (5) and (20);
4) We compute the derivative of the profit function with respect to the capital stock, $\partial \pi_{j,t_1} / \partial K_{j,t_1}$;
5) We compute the investment policy function at date t_1: $I_{j,t_1} = \gamma K_{j,t_1}$;
6) We update the capital stock of firm j at date t_2 using the perpetual inventory relation (1);
7) We solve for the equilibrium prices at date t_2 , and we obtain the derivative of the profit with respect to the capital stock, $\partial \pi_{j,t_2} / \partial K_{j,t_2}$;
8) We repeat the steps 5-7 for the next T periods;[25]
9) Then we compute the discounted sum of the future marginal benefits of investment in the network (that is the right-hand side of (21));
10) We construct the function:

$$f(\gamma) = i_{j,t_0} - \frac{\mu}{b}\left(\sum_{\tau=1}^{T} (\mu(1-d))^{\tau-1} \frac{\partial \pi_{j,t+\tau}}{\partial K_{j,t+\tau}} \right), \tag{23}$$

where $i_{j,t_0} = \gamma K_{j,t_0}$ and the second term is also a function of the investment policy parameter γ (according to step 9);

[25] We take $T = 30$ periods. We have checked that the results are robust when we forward-simulate over a bigger number of periods.

11) We find the parameter γ that solves the equation $f(\gamma)=0$ and we compute the investment at period t_0, i.e. $I_{t_0}=\gamma K_{j,t_0}$.

We repeat this algorithm for every period over a 30 year time horizon, by changing the starting date at the step 1 of the algorithm, $t = t_0 + 1, t_0 + 2, \ldots, t_0 + 29$. This gives a different investment policy function for each date.

Table 5 and Figure 6 present the results of the simulations for investment under the current market structure and the specific open-access policy for the firm j. This specific open-access policy leads to a decrease of investment by 10% per year, which leads to an increasing fall in the capital stock that reaches a loss of 10% in 30 years. (See Figure 7.) This is due to two effects. First, opening the network to a new firm leads to a decrease in equilibrium prices (namely, -6% per year) which is translated in a decrease in the future benefits from investing in the network.[26] Second, sharing the traffic leads to a lower market share for the incumbent between 10% and 13%.[27] (See Figure 8.) The smaller the proportion of train traffic operated by the owner of the infrastructure, the weaker the incentives to carry out such investment as the benefits of investment are shared by other independent train operating companies.

Furthermore, we compute the utility of the shippers who use the network of firm j, denoted $\bar{\delta}_{j,t}$, using the formula of the mean-utility, $\bar{\delta}_{j,t} = \theta k_{j,t} - \alpha \bar{p}_{j,t} + \bar{\xi}_{j,t}$, where $\bar{p}_{j,t}$ is the average price charged by firm j and the entrant, and $\bar{\xi}_{j,t}$ is the average of the intrinsic efficiencies of both firms, $(\xi_{j,t} + \xi_{n,t})/2$. Overall, Table 6 and Figure 9 show that the utility of shippers who use the network of firm j decreases exponentially to reach a loss of 10% after 30 years.

Appendix 3 provides several robustness results. It provides a different version of the algorithm, by allowing the capital stocks of competitors to increase over time, which are kept constant in the above algorithm. We assume that the investment policy function is the same for each firm.[28] Instead of solving for one equation (as in step 11 in the above algorithm), we solve for the parameter γ that minimizes the

[26] The decrease in the average price charged by the incumbent "Burlington Northern" and the entrant is between 10 and 16% per year.
[27] Since the size of the US freight market is fixed, a decrease in the market share of a firm is equivalent to a decrease of its freight volume/rail traffic.
[28] It is possible to specify different investment policy functions for each firm, but the computational burden increases significantly due to convergence issues.

norm $N(\gamma) = f(\gamma)' f(\gamma)$, where $f(\gamma)$ denotes the set of first-order conditions for the investment of the seven active firms in 2006.

In the simulation presented in this paper, an open-access policy where the access price is given at the marginal cost of providing access leads to a decrease in prices and a decrease in the investment incentives. In the long-run, this leads to a lower welfare for the shippers.

Overall, this paper shows that an open-access policy must be implemented carefully. The impact on the investment behavior may be important. An open-access market structure, by reducing anticipated rates and revenues, decreases the economic incentives for investment in network infrastructures. Therefore, in the long-run, the quality of the network might decrease and this has a negative impact on the performance of the US railroad industry.[29]

[29] There is a consensus recognizing that the improvement in the network after 1980 was a key element to explain the performance of the US railroad industry.

Table 5. Open-access, investment, and value of network infrastructures (in thousands, $1982)

	No open-access		Open-access	
Date	Capital stock	Investment	Capital stock	Investment
2006	8663.6396	1640.2087	8663.6396	1475.3097
2007	9663.6054	1647.1559	9498.7063	1477.3628
2008	10596.621	1649.9794	10274.115	1476.9314
2009	11463.510	1649.9276	10991.789	1474.8967
2010	12266.284	1647.9873	11654.393	1471.7805
2011	13007.793	1644.8200	12264.913	1468.0367
2012	13691.337	1640.9516	12826.573	1463.9379
2013	14320.499	1636.5923	13342.627	1459.6851
2014	14898.807	1632.0978	13816.292	1455.3919
2015	15429.883	1627.5287	14250.660	1451.1743
2016	15917.143	1622.9874	14648.711	1447.0954
2017	16363.853	1618.6269	15013.266	1443.1954
2018	16773.192	1614.4582	15346.981	1439.4988
2019	17148.111	1610.4532	15652.338	1436.0180
2020	17491.319	1606.6759	15931.648	1432.7574
2021	17805.386	1603.1327	16187.057	1429.7160
2022	18092.701	1599.8234	16420.549	1426.8883
2023	18355.474	1596.7434	16633.959	1424.2665
2024	18595.747	1593.8849	16828.976	1421.8411
2025	18815.407	1591.2383	17007.156	1419.6016
2026	19016.186	1588.7925	17169.929	1417.5370
2027	19199.683	1586.5360	17318.608	1415.6360
2028	19367.362	1584.4569	17454.399	1413.8878
2029	19520.571	1582.5436	17578.406	1412.2816
2030	19660.544	1580.7845	17691.644	1410.8070
2031	19788.415	1579.1686	17795.038	1409.4542
2032	19905.219	1577.6853	17889.439	1408.2139
2033	20011.909	1576.3246	17975.623	1407.0774
2034	20109.354	1575.0771	18054.302	1406.0364
2035	20198.349	1573.9338	18126.126	1405.0833
2036	20279.625	1572.8866	18191.688	1404.2111

Figure 6. Investment and open-access (in thousands, $1982)

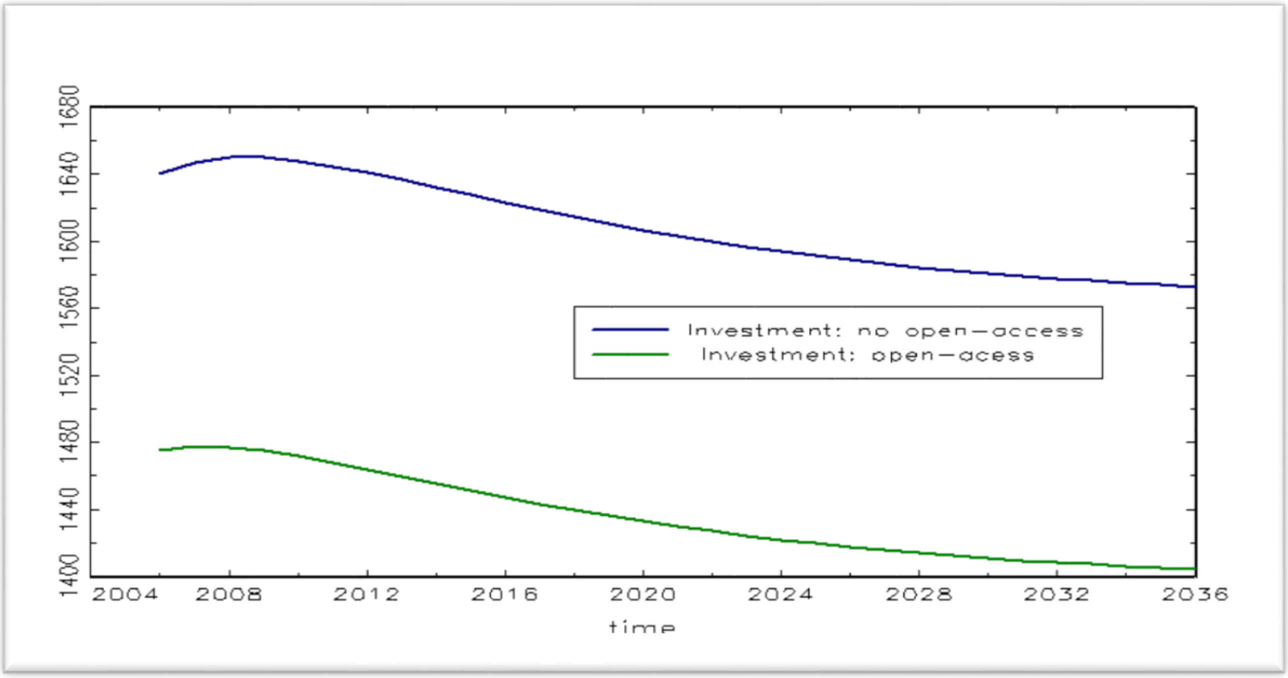


Figure 7. Capital stock and open-access (in thousands, $1982)

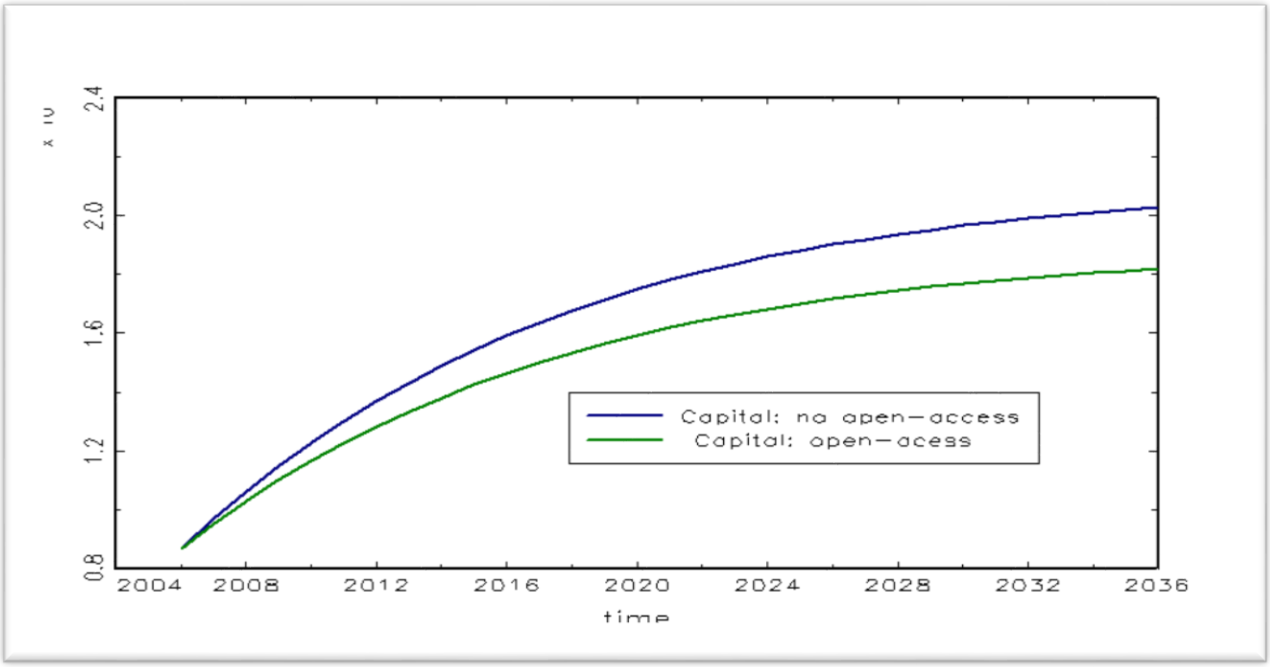


Figure 8. Market share of firm j and open-access

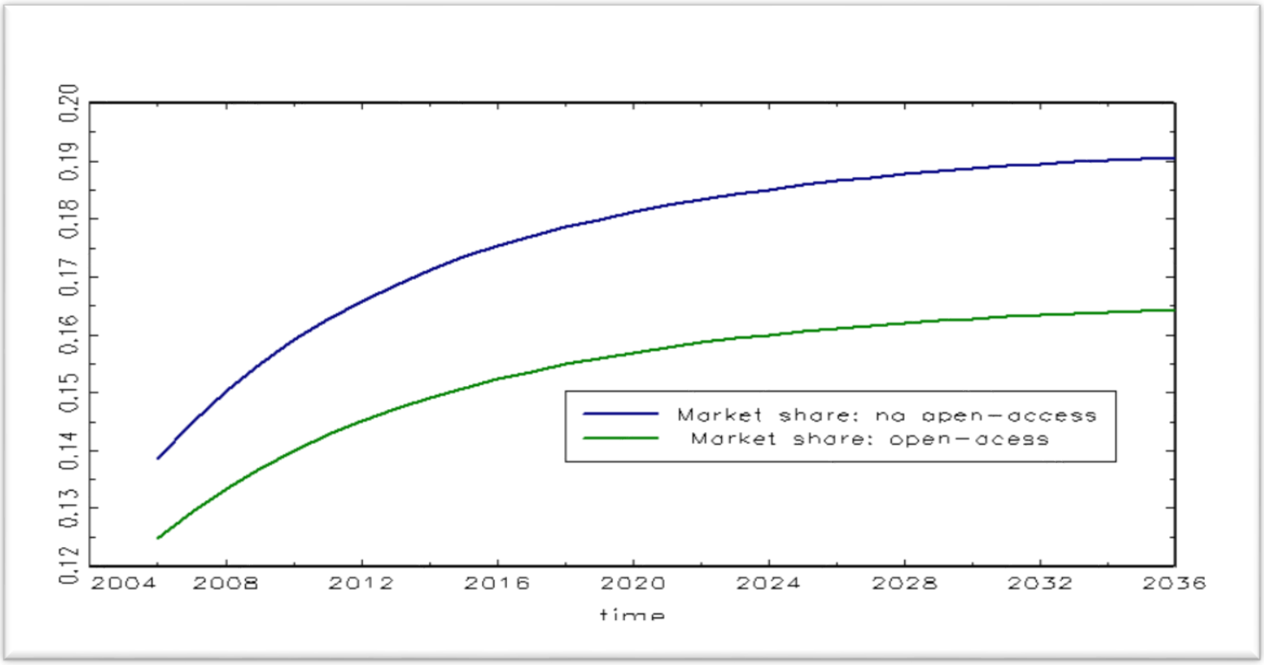


Figure 9. Utility on firm j network and open-access (in thousands, $1982)

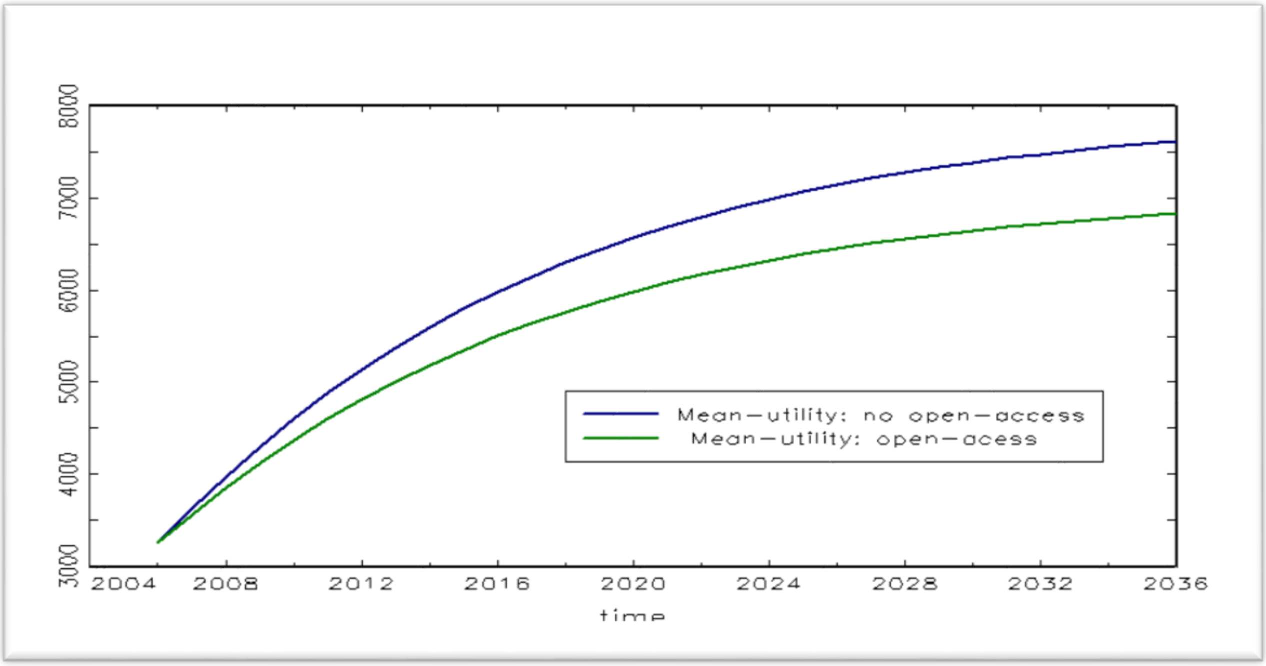


Table 6. Shippers' utility on firm j network (in thousands, \$1982)

Date	No open-access	Open-access	% Variation
2006	3252.3095	3252.5823	0
2007	3628.1357	3566.4303	-1.70
2008	3978.7995	3857.8569	-3.04
2009	4304.6103	4127.5850	-4.11
2010	4606.3243	4376.6157	-4.99
2011	4885.0123	4606.0719	-5.71
2012	5141.9150	4817.1642	-6.32
2013	5378.3786	5011.1165	-6.83
2014	5595.7292	5189.1373	-7.27
2015	5795.3284	5352.3889	-7.64
2016	5978.4599	5501.9911	-7.97
2017	6146.3512	5639.0047	-8.25
2018	6300.1966	5764.4272	-8.50
2019	6441.1057	5879.1917	-8.72
2020	6570.0967	5984.1669	-8.92
2021	6688.1355	6080.1590	-9.09
2022	6796.1196	6167.9142	-9.24
2023	6894.8799	6248.1216	-9.38
2024	6985.1842	6321.4162	-9.50
2025	7067.7408	6388.3829	-9.61
2026	7143.2017	6449.5590	-9.71
2027	7212.1668	6505.4383	-9.80
2028	7275.1872	6556.4736	-9.88
2029	7332.7691	6603.0804	-9.95
2030	7385.3766	6645.6392	-10.02
2031	7433.4353	6684.4987	-10.07
2032	7477.3351	6719.9781	-10.13
2033	7517.4332	6752.3694	-10.18
2034	7554.0567	6781.9399	-10.22
2035	7587.5048	6808.9338	-10.26
2036	7618.0514	6833.5747	-10.30

6 Conclusion

This paper proposes an empirical methodology for analyzing the trade-off between static and dynamic efficiency in the context of an open access policy. By opening the network to new firms, an open-access structure increases competition and presumably improves static efficiency. However, the entrant benefits from a high quality network without bearing the cost of investment (expropriation). By allowing entrants to free-ride on network investment, an open-access market structure discourages firms from making investments. This is supported by two arguments. First, to sustain innovation, and thus support dynamic efficiency, investment requires a rate of return which can be obtained through above-marginal cost pricing over time and this leads to a degree of allocative inefficiency. Indeed, some prospects of profits are necessary to motivate firms to make costly investment. Otherwise, a firm would not be able to recoup its fixed cost of investment. Second, the smaller the proportion of freight traffic carried by the owner of the infrastructure, the weaker its incentives to carry out such investment since the benefits of investment are shared by other independent train operating companies.[30] Thus, by decreasing anticipated rates and revenues, an open-access market structure decreases the incentives to invest in the network infrastructure. The analysis presented in this paper can be extended in several ways.

First, when we simulate an open-access policy, we assume that marginal costs are constant over time. In this way, we focus only on the hold-up issue. This is an important assumption. The previous analyses of the US railroad industry have highlighted the importance of operational economies of density (see Ivaldi and McCullough, 2001, 2008). Thus, dividing the volume of freight on a particular network among operators is likely to increase average costs. This is the cost-efficiency argument. Accounting for this effect, the decrease in the anticipated future mark-ups should be more important and the negative impact on the investment would be even larger with an open-access policy.

Another extension is related to the optimal design of the access charge. In this paper, we assume a linear access charge equal to the marginal cost of providing access. This allow us to illustrate in particular the expropriation issue. Since investment plays a crucial role on the long term performance of the industry, maintaining incentives for infrastructure investment should be a major consideration in designing the access charge. As a next step, other types of access charge can be simulated. For instance, the linear access charge could be set at a higher level to preserve the incentives to invest in the network. However, if the access price is too high, then access would not lead to a significant decrease in prices. The framework of this paper also allows to consider other types of (more evolved) access charges (for example a two-part access charge with a variable and a fixed components), which might even allow to relax the tension between static efficiency and dynamic efficiency.[31] This topic on the optimal design of access charge deserves further theoretical and empirical research and is beyond the scope of this paper.

[30] This second effect could also be positive for the revenue of the incumbent (see Section 3.2

[31] In a two-part access charge, the fixed component could be interpreted as a subsidy from the Government in order to preserve the incentives to invest in the network.

APPENDIX 1: CONCENTRATION IN THE US RAIL FREIGHT INDUSTRY

This appendix presents the concentration over time in the US rail freight industry. Figure 10 and Figure 11 list all the takeovers that happened in the railroad industry. In this paper, we do not consider a takeover as an investment. This is beyond the scope of this paper and can be related to the literature on endogenous mergers. (See Gowrisankaran, 1999.) We focus on the issue of panel attrition due to concentration in the US rail freight industry.

In the data, there are two problematic elements in the construction of merged firms, namely the merged firms *CSX* and *NS* in 1986. These two firms appear in 1986 and are the results of the mergers of several firms. The firms *BO* and *CO* were merged into the Chessie System, and that system was then merged into *SBD* in 1986. For *NS*, we assume that the merger parties have sold their assets to the firm with the highest market share before the merger.[32] Thus, we assume that the firm *NW* has sold its assets to *SOU* in 1986. This treatment of merger yields an unbalanced panel data with an attrition characteristic such that (see Wooldridge, 2002, Chapter 17):

$$r_{j,t} = 1 \Rightarrow r_{j,\tau} = 1, \text{ for all } \tau \leq t - 1.$$

This attrition characteristic of the data is an important technical issue for the demand estimation. (See Coublucq, 2013.)

[32] This assumption reflects what we observe in the data for all the railroad firms.

Figure 10. Railroad firms in the Eastern area

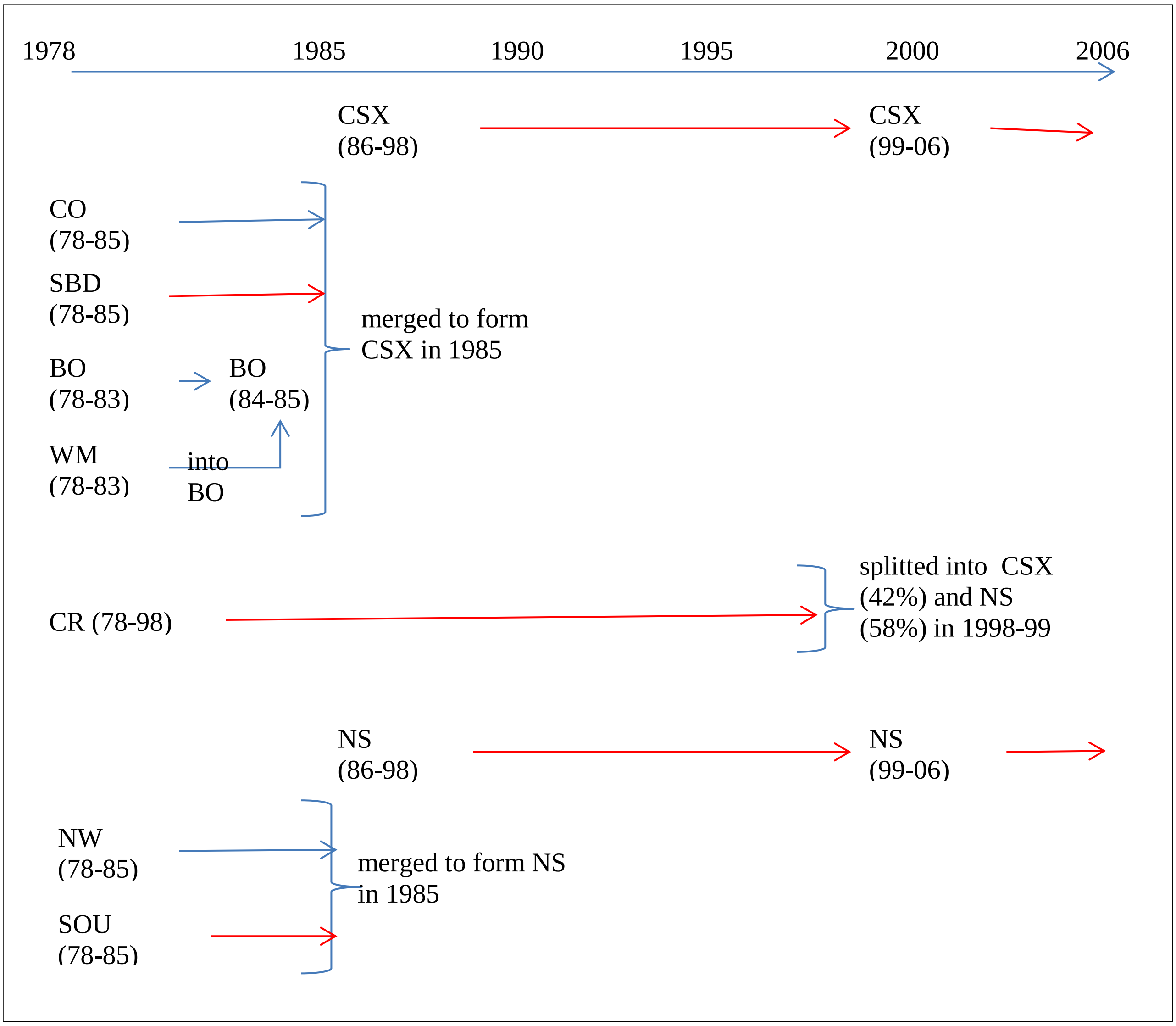
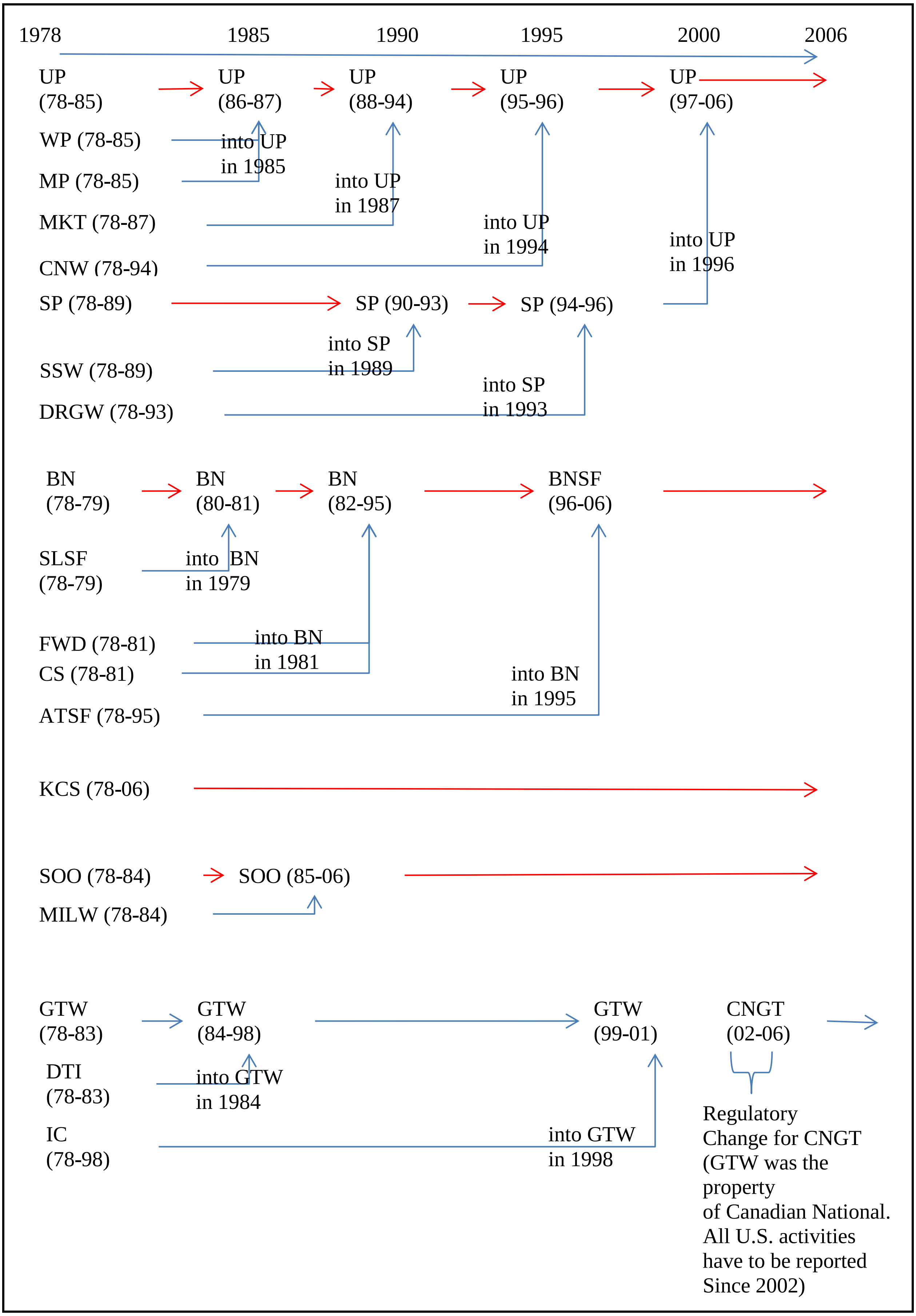


Table 7. Railroad firms in the Eastern area

Railroad	Years in data	Abbrevation (used in Figure 10)
Baltimore & Ohio (BO)	1978-1985	BO (into CSX in 1985)
Chesapeake & Ohio (CO)	1978-1985	CO (into CSX in 1985)
Consolidated Rail Corp. (CR)	1978-1998	CR (split between CSX and NS in 1999)
CSX Transportation (CSX)	1986-2006	CSX
Norfolk Southern (NS)	1986-2006	NS
Norfolk & Western (NW)	1978-1985	NW (into NS in 1985)
Seaboard System Railroad (SBD)	1978-1985	SBD (into CSX in 1985)
Southern Railway System (SOU)	1978-1985	SOU (into NS in 1985)
Western Maryland (WM)	1978-1983	WM (into BO in 1983)

Figure 11. Railroad firms in the Western area



1978
1985
1990
1995
2000
2006
UP (78-85)
UP (86-87)
UP (88-94)
UP (95-96)
UP (97-06)
WP (78-85)
into UP in 1985
MP (78-85)
into UP in 1987
MKT (78-87)
into UP in 1994
CNW (78-94)
into UP in 1996
SP (78-89)
SP (90-93)
SP (94-96)
into SP in 1989
SSW (78-89)
into SP in 1993
DRGW (78-93)
BN (78-79)
BN (80-81)
BN (82-95)
BNSF (96-06)
SLSF (78-79)
into BN in 1979
FWD (78-81)
into BN in 1981
CS (78-81)
into BN in 1995
ATSF (78-95)
KCS (78-06)
SOO (78-84)
SOO (85-06)
MILW (78-84)
GTW (78-83)
GTW (84-98)
GTW (99-01)
CNGT (02-06)
DTI (78-83)
into GTW in 1984
IC (78-98)
into GTW in 1998
Regulatory Change for CNGT (GTW was the property of Canadian National. All U.S. activities have to be reported Since 2002)

Table 8. Railroad firms in the Western area

Railroad	Years in data	Abbreviation (used in Figure 11)
Atchison, Topeka & Santa Fe (ATSF)	1978-1995	ATSF (into with BN in 1995)
Burlington Northern (BN) ; Burlington Northern Sante Fe (BNSF)	1978-2006	BN ; BNSF
Canadian National Grand Trunk Corporation (CNGT)	2002-2006	CNGT (it incorporates all US activities of Canadian National Railroad, which included GTW activities)
Chicago & Northwestern (CNW)	1978-1994	CNW (into UP in 1994)
Colorado and Southern (CS)	1978-1981	CS (into BN in 1981)
Denver, Rio Grande & Western (DRGW)	1978-1993	DRGW (into SP in 1993)
Detroit, Toledo & Ironton (DTI)	1978-1983	DTI (into GTW in 1983)
Forth Worth and Denver (FWD)	1978-1981	FWD (into BN in 1981)
Grand Trunk & Western (GTW)	1978-2001	GTW
Illinois Central (Gulf) (IC)	1978-1998	IC (into GTW in 1998)
Kansas City Southern (KCS)	1978-2006	KCS
Milwaukee Road (MILW)	1978-1984	MILW (into SOO in 1984)
Missouri-Kansas-Texas (MKT)	1978-1987	MKT (into UP in 1987)
Missouri Pacific (MP)	1978-1985	MP (into UP in 1985)
Saint Louis and San Francisco (SLSF)	1978-1979	SLSF (into BN in 1979)
Saint Louis, Southwestern (SSW)	1978-1989	SSW (into SP in 1989)
SOO Line (SOO)	1978-2006	SOO
Southern Pacific (SP)	1978-1996	SP (into UP in 1996)
Union Pacific (UP) ; Union Pacific-Southern Pacific (UPSP)	1978-2006	UP ; UPSP
Western Pacific (WP)	1978-1985	WP (into UP in 1985)

APPENDIX 2. ALGORITHM FOR DEMAND ESTIMATION

This section is based on Coublucq (2013), where additional details are available.

First, we discuss the endogeneity of the variables included in the estimating Equation (16). The price, denoted $p_{j,t}$, and the within market share, denoted $\ln s_{j,t|g}$, are endogenous. Thus, the variables $\Delta p_{j,t}$ and $\Delta \ln s_{j,t|g=1}$ are also endogenous. The discussion becomes more subtle for the variables $\Delta k_{j,t}$ and $\Delta\lambda_{j,t-1}$. Using the structure of the model, we know that the variables $k_{j,t}$ and $\lambda_{j,t-1}$ are weakly exogenous. Indeed, $k_{j,t} = \ln(K_{j,t})$, and the capital stock is constructed using the relation

$K_{j,t} = K_{j,t-1}(1-\delta) + I_{j,t-1}$, where $I_{j,t-1}$ represents the investment in the network at date $t-1$. From the dynamic model, we know that the investment is endogenous and it is a function of the previous state of the industry, $\boldsymbol{w}_{t-1}$. This implies that the capital stock $K_{j,t}$, and thus the proxy for network quality $k_{j,t}$, are a function of w_{t-1}. By construction, the error term $e_{j,t}$ in Equation (14) is uncorrelated with the previous state of the industry $\boldsymbol{w}_{t-1}$. Thus, the proxy for the network quality, $k_{j,t}$, is weakly exogenous since it is uncorrelated with the contemporaneous and the future error terms, $e_{j,s}, s \geq t$, and correlated with the past error term, $e_{j,s}, s \leq t-1$. This implies that in the estimating Equation (16), the variable $\Delta k_{j,t} = k_{j,t} - k_{j,t-1}$ is endogenous since $k_{j,t}$ is correlated with $\Delta e_{j,t}$ through $e_{j,t-1}$. Nevertheless, we can instrument $\Delta k_{j,t}$ by using $K_{j,t-1}$ as instrument since the lag of the capital stock is a function of the state of the industry at date $t-2$, $\boldsymbol{w}_{t-2}$, and the error term $\Delta e_{j,t}$ is uncorrelated with the state of the industry at date $t-2$ (for the estimation, we have also added $K_{j,t-2}$ as an instrument). Lastly, we discuss the endogeneity of the first-difference of the Mills ratio, $\Delta\lambda_{j,t-1} = \lambda_{j,t-1}(\boldsymbol{w}_{t-1}) - \lambda_{j,t-2}(\boldsymbol{w}_{t-2})$. Like the stock of capital, the Mills ratio $\lambda_{j,t-1}(\boldsymbol{w}_{t-1})$ is also weakly exogenous since it is uncorrelated with $e_{j,s}, s \geq t$ and it is correlated with $e_{j,s}, s \leq t-1$. In the estimating Equation (16), $\Delta\lambda_{j,t-1}$ is endogenous since $\lambda_{j,t-1}$ is correlated with $e_{j,t-1}$ and thus with $\Delta e_{j,t}$. We instrument $\Delta\lambda_{t-1} = \lambda_{j,t-1} - \lambda_{j,t-2}$ by the second lag of the Mills ratio, $\lambda_{j,t-2}$.

To summarize, the choice of the instruments is guided by the structure of the model. Hence, during the estimation, accepting the over-identifying restriction may be interpreted as accepting the structure of the model as well.

We now provide the estimation algorithm to deal with the attrition issue due to concentration. This is important since attrition creates a bias in the price and the capital parameters. (See Coublucq, 2013, for further details.)

In the estimating Equation (16), we have assumed that we know the previous state of the industry, $\boldsymbol{w}_{t-2}$, since we use the condition $E[\Delta e_{j,t} \mid \boldsymbol{z}_j, \boldsymbol{w}_{t-2}, \boldsymbol{r}_j] = 0$. To make the estimation feasible, we need to use the following iterative algorithm:

1) Start with an initial guess of the vector of demand parameters, denoted $\widehat{\boldsymbol{\mu}} = (\hat{\theta}, \hat{\alpha}, \hat{\sigma})$.
2) Using Equation (12), we compute an estimate of the unobserved state variable that represents the unobserved firm efficiency, $\xi_{j,t}$.
3) We compute the probabilities of remaining in the industry as a function of the industry state, $\hat{P}_{j,t}(\widehat{\boldsymbol{w}}_t)$, where $\widehat{\boldsymbol{w}}_t = (J_t; K_{j,t}, \boldsymbol{K}_{-j,t}; \hat{\xi}_{j,t}, \hat{\boldsymbol{\xi}}_{-j,t})$, using a probit model, and $\boldsymbol{K}_{-j,t}$ and $\boldsymbol{\xi}_{-j,t}$ represent respectively the sum of the observed and the unobserved state variable for the competitors.
4) The threshold value $\bar{\Phi}_{j,t-1}(\widehat{\boldsymbol{w}}_{t-1}) = F^{-1}(\hat{P}_{j,t-1}(\widehat{\boldsymbol{w}}_{t-1}))$ is computed and we obtain the Mills ratio $\hat{\lambda}_{j,t-1}(\widehat{\boldsymbol{w}}_{t-1})$ as a correction term for attrition (see Equation (15)). We are also able to recover $\hat{\lambda}_{j,t-2}(\widehat{\boldsymbol{w}}_{t-2})$.
5) We estimate Equation (16) by an instrumental variable regression using the instruments $\boldsymbol{z}_{j,t}$, $\boldsymbol{z}_{j,t-1}$, $K_{j,t-1}$, $K_{j,t-2}$, and $\lambda_{j,t-2}$.
6) Using the new demand estimates $\widehat{\boldsymbol{\mu}} = (\widehat{\boldsymbol{\beta}}, \hat{\theta}, \hat{\alpha}, \hat{\sigma})$, we repeat steps 2-5 until convergence of the demand estimates.

APPENDIX 3: ROBUSTNESS CHECK ON THE INVESTMENT POLICY FUNCTION

This part of the appendix provides the results of an open-access market structure when the algorithm allows for an increase in the capital stocks of the competitors (they were kept constant in the initial algorithm). We assume that the investment policy function is the same for each firm. Instead of solving one equation (see step 11 in the algorithm, section 5), we solve for the parameter γ that minimizes the norm $N(\gamma) = f(\gamma)' f(\gamma)$, where $f(\gamma)$ denotes the set of first-order conditions for the investment of the seven active firms in 2006.

The results are very similar. The average price in the industry decreases by 6% and firm j carries less freight volume (see Figure 12). These two elements decrease the benefits from investing in the network. Indeed, the investment of firm *j* decreases by 10% per year (see Figure 13 and Figure 14). Overall, the consumer welfare decreases (see Figure 15) and the difference between the two welfares is increasing over time to reach a gap of 10% after 30 years.

Figure 12. Market share of firm *j* and open-access

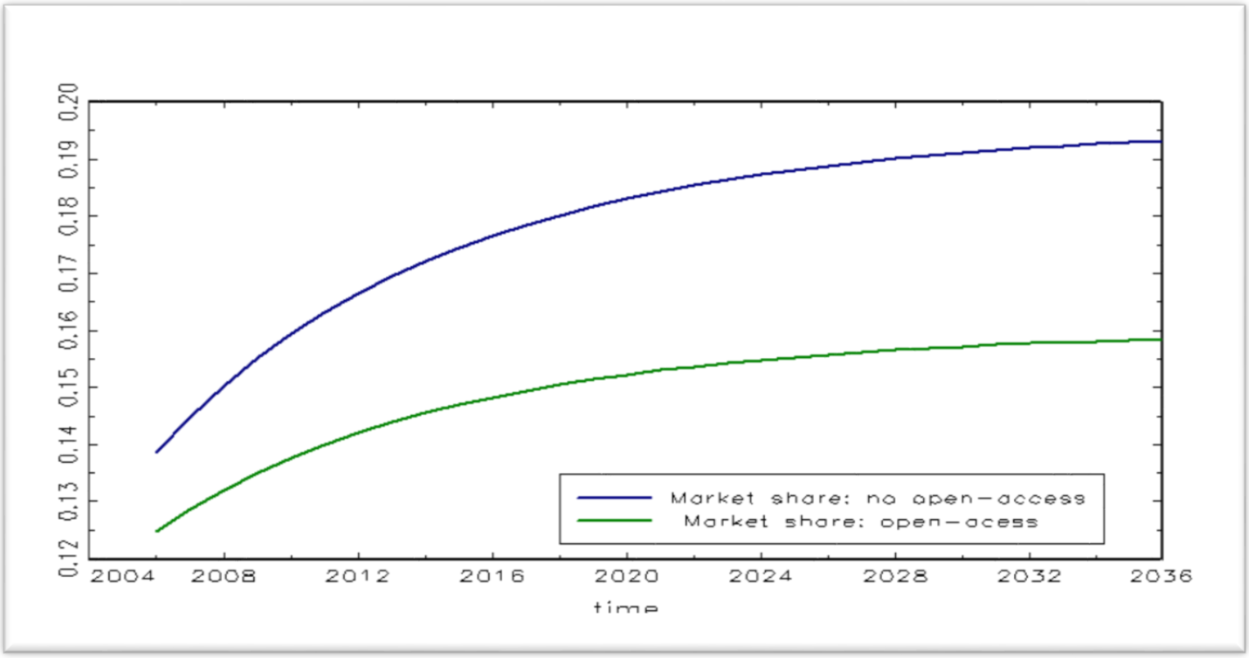


Figure 13. Investment and open-access (in thousands, $1982)

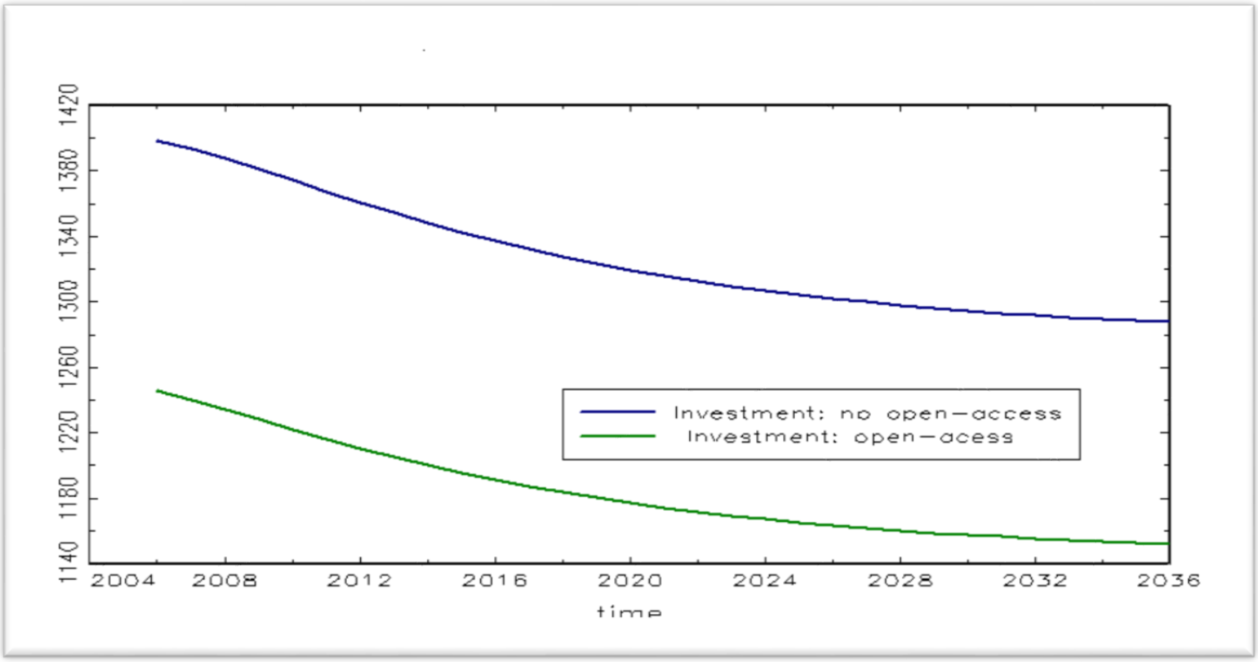


Figure 14. Capital stock and open-access (in thousands, $1982)

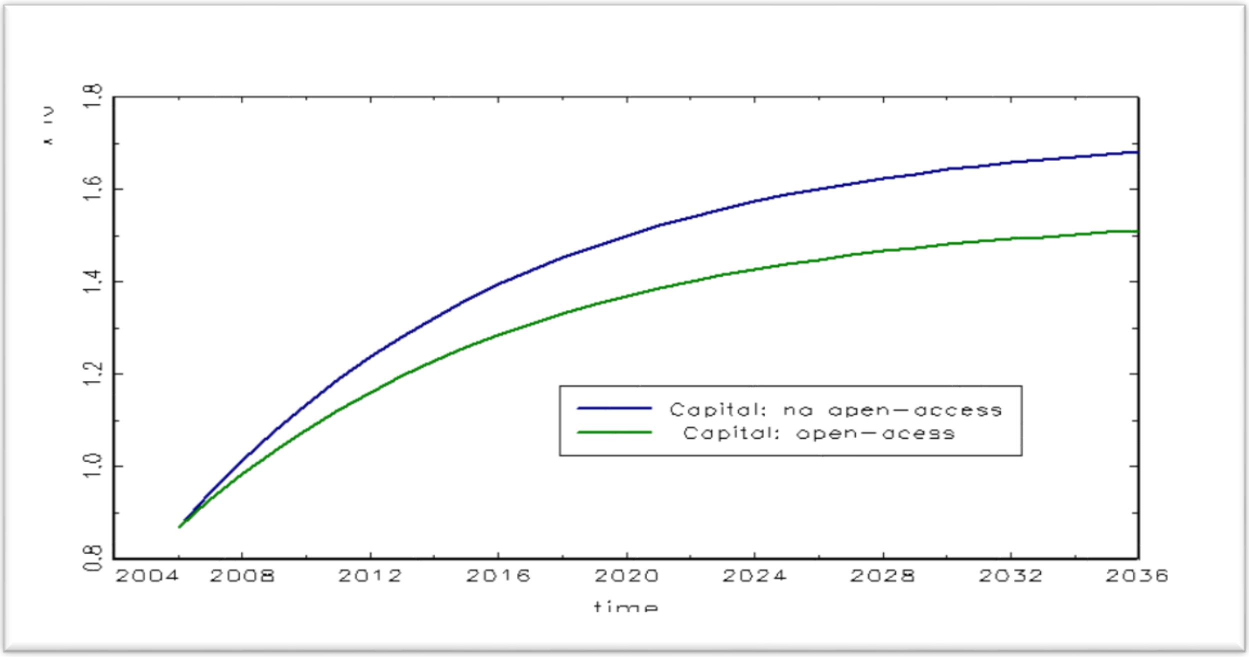
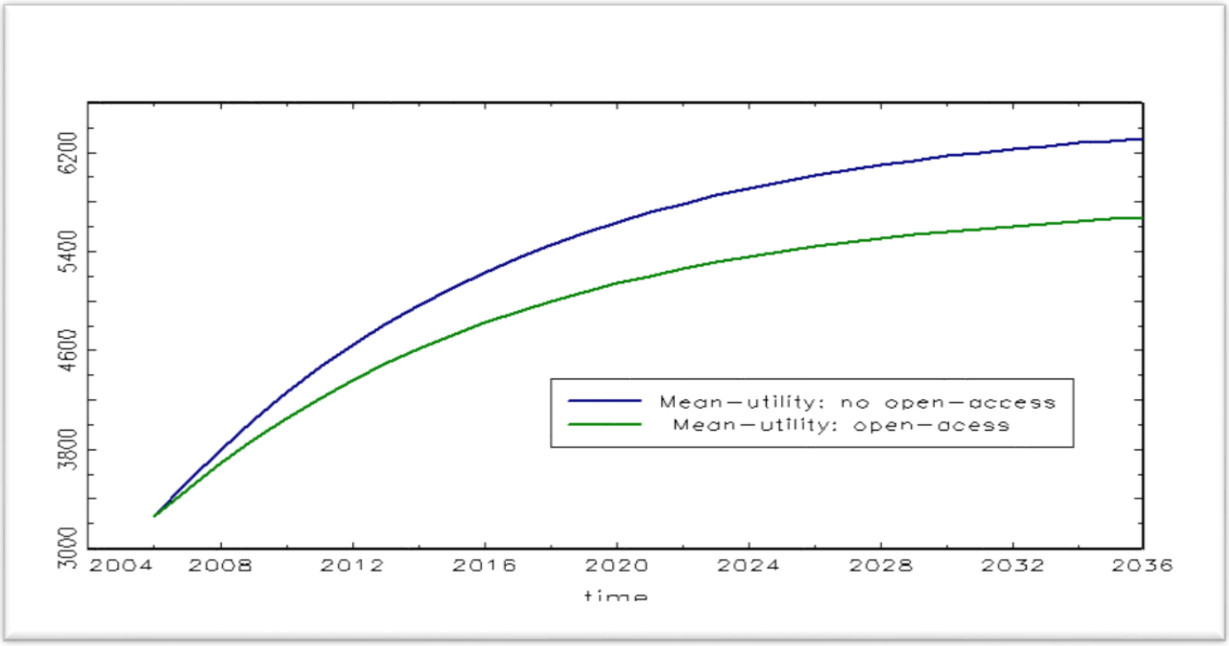


Figure 15. Utility on firm *j* network and open-access (in thousands, $1982)



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