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Freight modal policies toward a sustainable society

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Abstract. Freight transport policy analysts attempt to shift truck freight movements to rail so as to diminish transportation externalities including environmental costs and safety issues. Therefore, policy-makers need to be aware of the consequences of their decisions beforehand. This study is mainly focused on two policies targeting fuel price and access to rail transportation. A nation-wide freight mode choice model was developed for Iran, and shippers' tendency to choose rail or truck freight transportation was analyzed by considering the shipping time and cost, commodity weight, commodity type, and rail accessibility. Total fuel consumption and air pollution costs were compared in various scenarios. Based on the results, environmental transportation costs are significantly reduced as a result of the modal shift from truck to rail freight transportation if the government reallocates gasoline subsidy to the construction of prioritized railroads.

1. Introduction

In 2010, eighty-nine percent of the ton-km transported freight was moved by trucks in Iran. Its associated environmental externalities are almost 9.5 times the rails [1,2]. Reducing high external costs of truck movements in terms of fuel consumption and air pollution requires appropriate actions to shift from truck to more environmental-friendly alternatives such as rail freight transportation. Therefore, using proper tools to analyze the truck-rail competition is essential to improving the efficiency of freight transportation. The reason for choosing certain types of ground freight is elemental to developing effective policies. Among these reasons are:

1. 11.3-billion-dollar subsidy for truck freight transportation;
2. Low accessibility to the rail network considering that only 30% of Iranian cities had direct rail access in 2010.

A city has direct access to rail when the distance between the city center and a rail station is less than 50 kilometers.

In the past decades, early mode choice models were primarily based on the shipping cost and time [3], while other influential variables such as flexibility, reliability, and safety were added to the behavioral models [4–6]. Brooks et al. [7] reported the presence of meaningful trade-offs between shipping cost and benefits of reducing transit time, improving on-time arrival reliability, and mitigating the risk of long arrival delays. Hwang [8] developed a binomial logit market share model for mode choice decisions to evaluate the effects of several variables including crude oil price, commodity value, and average shipment distance for rail and truck. This attempt was one of the recent efforts to account for environmental impacts such as CO_2, CH_4, and N_2O emissions in modal freight de-

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Table 1. Summary of some previous studies.

Year	Researcher(s)	Location	Approach*	Modes**	Significant variables: Commodity type	Value	Time	Cost	Reliability & Responsiveness	Frequency	Loss/Damage
2000	Cullinane	Western route/mode choice literature	Content analysis		✓		✓	✓	✓		✓
2002	Shinghal	India	MNL	T/R	✓		✓	✓	✓	✓	
2003	Norojono et al.	Indonesia	OP	T/R		✓	✓	✓	✓	✓	✓
2007	Arunotayanun et al.	Indonesia	MNL/ML	T/R		✓	✓		✓	✓	
2007	Tsamboulas et al.	Greece-Turkey	MNL	T/R			✓	✓	✓		
2007	Danielis & Marcucci	Italy	MNL/RPL	T/R			✓	✓	✓	✓	✓
2011	Samimi et al.	U.S.	BL/P	T/R	✓		✓	✓			
2011	Baindur et al.	France-Italy	NL	T/R/W	✓		✓	✓		✓	✓
2012	Brooks et al.	Australia	ML/MNL	T/R/W			✓	✓	✓		
2013	Pourabdollahi et al.	U.S.	Copula-based joint MNL-MNL	T/R/A	✓			✓	✓		
2014	Hwang	U.S.	BL	T/R	✓	✓	✓	✓			
2015	Jaensirisak	Thailand	Based on 4-steps	T/R/W			✓	✓	✓		
2015	Arencibia et al.	Spain	MNL	T/R/W			✓	✓	✓	✓	

*: P: Probit; OP: Ordered Probit; NL: Nested Logit; ML: Mixed Logit; MNL: Multinomial Logit; MMNL: Mixed Multinomial Logit; RPL: Random Parameter Logit;

**: T: Truck; R: Rail; W: Water; A: Air.

cisions. Environmental externalities of transportation systems were focused in the past decades. McKinnon and Piecyk [9], for instance, found that freight transport was the largest contributor to the carbon dioxide produced in the U.K. with a share of 6%. In Iran, the trucking sector produced approximately 9% of the total carbon dioxide emissions in 2010 [2].

Tremendous efforts have been made to shift freight traffic from road to rail to control energy use and air pollution and to ensure traffic safety. Therefore, some freight mode choice studies have looked into policy-sensitive variables that may be used to influence modal decisions. Samimi et al. [6] argued that rail shippers were more sensitive to costs, while truck users were more concerned about haul time in the U.S. They also found that increasing fuel price was less likely to shift shippers from truck to rail. Later, Hwang [8] analyzed the effect of crude oil price on modal decisions. He found that seven-fold increase in fuel price caused an approximately 40% reduction in truck share and thereby, a 50% decrease in CO_2 emissions. Table 1 provides a summary of some previous studies on freight mode choice.

This research is an attempt at measuring the effect of the reduction of subsidy on fuel and expansion of rail network, allowing rail discount on mode choice decisions in a layout of 30 diverse scenarios, and quantifying potential environmental benefits. In particular, the models presented in this paper are:

1. Developed using public data, which is cost-efficient and easy to update;
2. Capable of evaluating a range of pro-environment policies.

Most of the freight mode choice studies are based upon costly shipper-carrier surveys with a diverse range of behavioral variables that are too challenging to collect. Models that are calibrated by high-quality data could hardly be afforded in developing countries with limited research budgets. Current research is an effort to fill this gap.

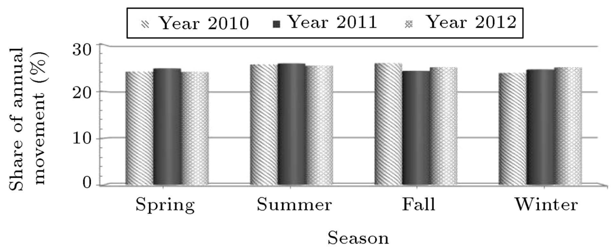
2. Data

More than 155-thousand-km rail and 8.7 million truck shipment records for the second month of each season in 2011 were acquired from Iran's Railway Organization and Iran's Road Maintenance and Transportation Organization. Origin, destination, commodity type, value of commodity, weight, shipping cost, and travel mode were reported for each record. Further, 378 counties in Iran are considered as the shipment's origin and destination. Shipment types were classified by 23 commodity categories (see Table A.1) based on the Standard Classification of Transported Goods (SCTG) [10]. Before the analysis, outliers were detected using the mahalanobis distance measure [11], followed by an expert review for data cleaning. Then, 0.5% of the observations with unusual values for shipping cost were eliminated from the dataset. Figure 1 illustrates the share of ton-km rail for each commodity and a general market share of the commodity based on ton-km moved. A descriptive analysis of the data revealed that growth of rail ton-km movements for raw material, construction, petroleum, and mineral commodity groups increased from 7.6 to 9.2 % between 2010 and 2015 in Iran. Moreover, Wallis [12] highlighted the importance of studying the seasonal behavior of the data. Figure 2 represents seasonal fluctuations of truck versus rail ton-km in Iran. As shown in Figure 2, no tangible seasonal fluctuations are in the data and seasonal adjustment is hardly required.

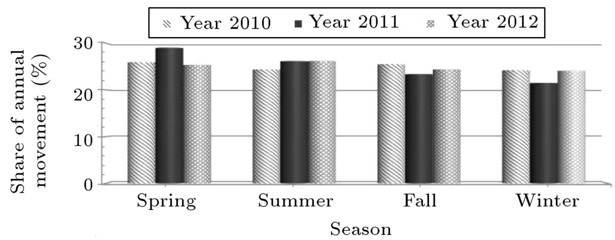
Explanatory variables required for the analysis have been selected based on the literature presented in Table 1 and local experts' recommendations. Reis [13] reviewed 17 freight mode choice papers and discussed the variables involved in advanced freight mode choice models. Further, de Jong et al. [14] elaborated data needs for the "standard" freight mode choice model in four categories including:

1. Data on GDP, employment, cultural resistance between zones;
2. A base OD matrix by mode;
3. Time and distance between origins and destinations by mode;
4. Transport cost functions.

Although some behavioral variables (e.g., reliability and flexibility of a mode) are critical for logistical components of a freight model, all the "classic" data categories are available in the data. This is further elaborated in the following section. However, some information was provided from other data sources or estimated indirectly. In particular, shipping time was not available in the primary records. Travel time and distance were determined using Google Maps tools in the road network, given the origin and destination



(a) Truck



(b) Rail

Figure 2. Seasonal fluctuation of ton-km freight movement by mode.

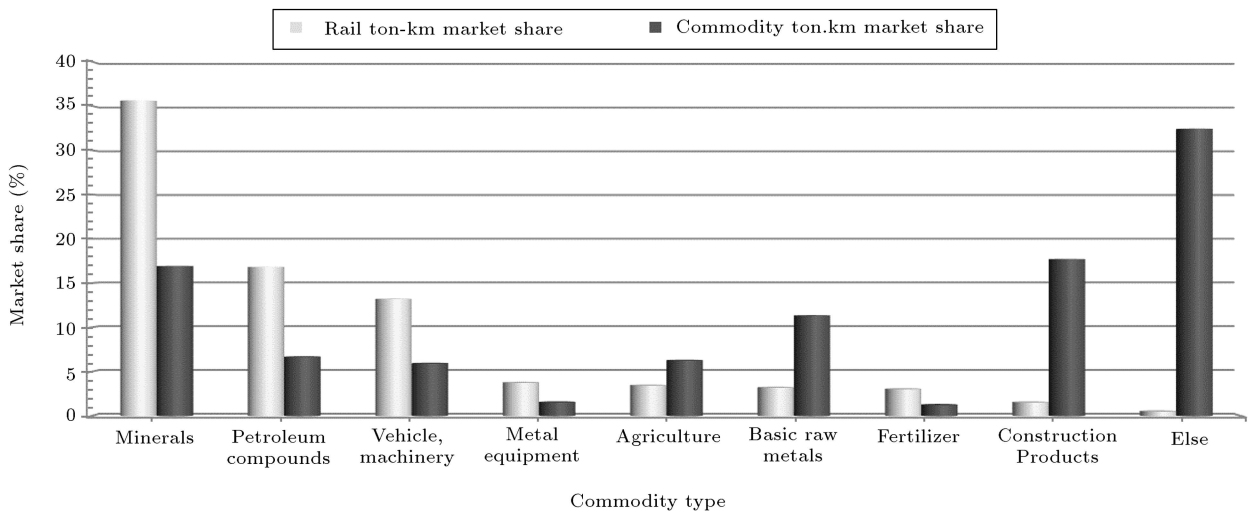


Figure 1. Rail ton-km share and general market share of each commodity.

zones of each record. These values were then assigned to the shipment records by a MATLAB code. For intermodal shipments, the estimated travel time and distance include truck access to the nearest rail station, in addition to the rail haul time and distance. Industrial development level of each region measured by the number of employees in the industry sectors and obtained from Iran's Ministry of Industry, Mine and Trade in 2011 [15] was also taken into account.

To sensitize the calibrated mode choice model to energy price, it is essential to consider the shipping cost of each alternative. To this end, linear regression is employed to estimate the unobserved shipping costs in each commodity group. Since some commodities are entirely transferred by trucks, adopting a mode choice model for such commodities is nonsensical. Some other commodity types, also, do not account for a considerable proportion of the country's commodity transactions (see Figure 1). Keeping these in mind, the prospective model was narrowed down to four groups: mineral, petroleum, construction, and raw metal goods. They accounted for 56% of the ton-km of freight. Table 2 presents descriptive statistics of the explanatory variables, and Table 3 summarizes the regression cost models. Shipping distance was calculated based on the shortest path between each origin and destination pair

Table 2. Explanatory variables of cost models.

Variable	Description	Average (standard deviation) in							
		Truck models				Rail models			
		Basic raw metals	Min.[a]	Const.[b]	Petroleum	Basic raw metals	Min.	Const.	Petroleum
WT	Wight of shipment (Ton)	19.8 (5.3)	20.2 (4.9)	16.4 (6.3)	19.6 (4.8)	50.8 (8.6)	75.4 (18.4)	60.3 (7.8)	54.0 (6.2)
DIST	Truck highway time (min), Rail track distance (km)	394 (274)	453 (327)	232 (229)	238 (241)	475 (365)	541 (381)	238 (280)	674 (333)
MAY	1: If shipping was in May 0: Otherwise	0.283 (0.450)	0.282 (0.450)	0.286 (0.450)	0.235 (0.424)	0.310 (0.462)	0.242 (0.428)	0.370 (0.483)	0.305 (0.461)
AUG	1: If shipping was in Aug. 0: Otherwise	0.254 (0.435)	0.250 (0.433)	0.271 (0.444)	0.241 (0.428)	0.228 (0.419)	0.262 (0.440)	0.296 (0.457)	0.230 (0.421)
NOV	1: If shipping was in Nov. 0: Otherwise	0.224 (0.417)	0.200 (0.400)	0.231 (0.422)	0.259 (0.437)	0.194 (0.395)	0.223 (0.416)	0.202 (0.401)	0.242 (0.428)
FEB	1: If shipping was in Feb. 0: Otherwise	0.239 (0.426)	0.269 (0.443)	0.211 (0.409)	0.265 (0.441)	0.269 (0.443)	0.272 (0.445)	0.131 (0.338)	0.223 (0.417)
OABAS	1: If origin was Bandar Abbas 0: Otherwise	0.0453 (0.208)	0.0087 (0.093)	0.0041 (0.064)	0.0676 (0.251)				
OMAH	1: If origin was Mahshahr 0: Otherwise	0.0329 (0.178)	0.0295 (0.169)	0.0003 (0.016)	0.0295 (0.169)				
DABAS	1: If destination was Bandar Abbas 0: Otherwise	0.0383 (0.192)	0.2963 (0.457)	0.0144 (0.119)	0.0433 (0.204)				
DMAH	1: If destination was Mahshahr 0: Otherwise	0.0060 (0.077)	0.0664 (0.249)	0.0054 (0.073)	0.0158 (0.125)				

[a]Minerals; [b]Construction.

Table 3. Cost estimation model.

Variables	Coefficient (t-value)							
	Truck models				Rail models			
	Basic raw metals	Minerals	Construction	Petroleum	Basic raw metals	Minerals	Construction	Petroleum
CONSTANT	162252 (787.4)	80032 (279.8)	89796 (1052.2)	50948 (304.7)	147641 (29.9)	402748 (287.6)	418224 (154.0)	171317 (40.9)
WT × DIST × MAY	31.526 (1003.7)	31.615 (792.3)	30.057 (1254.4)	28.755 (754.7)	26.646 (123.1)	26.110 (711.1)	14.497 (86.0)	32.242 (253.3)
WT × DIST × AUG	32.829 (1040.0)	33.485 (807.3)	32.106 (1326.9)	30.430 (686.6)	26.103 (107.3)	27.258 (697.5)	18.291 (72.7)	34.123 (271.8)
WT × DIST × NOV	33.954 (1054.8)	30.196 (686.4)	33.041 (1323.5)	31.524 (759.2)	31.154 (100.7)	27.514 (650.2)	13.154 (58.4)	33.012 (225.0)
WT × DIST × FEB	34.737 (1109.1)	35.737 (871.7)	33.283 (1296.2)	33.379 (886.8)	32.022 (163.8)	28.861 (661.9)	16.352 (80.6)	37.850 (294.8)
OABAS	8.658 (246.2)	14.244 (138.4)	14.860 (283.5)	15.768 (221.6)				
OMAH	5.523 (107.6)	23.240 (203.6)	40.142 (44.8)	–4.919 (–56.9)				
DABAS	–8.914 (–191.8)	–0.549 (–17.3)	–9.323 (–182.7)	–7.379 (–167.2)				
DMAH	–6.842 (–58.7)	–12.160 (–220.1)	–8.362 (–66.3)	–3.285 (–44.9)				
No. of observations	667,351	565,606	2,260,360	557,407	9,595	96,903	12,435	20,088
R-squared	0.826	0.804	0.690	0.762	0.792	.901	0.558	0.849
F-test	397032	290386	629089	222697	9135	221655	3917	28287

in the road and rail networks. This model implicitly accounts for the effect of road difficulty as well as the difference in the transportation cost of the routes starting to/from two major ports, namely Bandar-Abbas and Mahshahr. All the cost models meet the primary assumptions of the classical linear regressions; consequently, coefficients were interpreted using the t-statistics and the explanatory power.

3. Model

The mode choice model is derived for truck and rail/truck (intermodal) modes since more than 98% of freight movements in Iran is transported through these modes. The intermodal mode includes a road section intended for reaching the nearest railway station adding up to the rail section. Table 4 presents a brief description of the mode choice model variables with respect to four types of commodities.

Logit model is the most widely used discrete choice model with readily interpretable results [16]. Accordingly, four binary logit models were developed to explain freight modal selection behavior. Eqs. (1) and (2) represent the relative utility of rail compared to truck and the probability of choosing truck in a binary choice situation, respectively. β's represent the parameters of the model that are estimated by maximizing the log-likelihood function (Eq. (3)). In Eqs. (1) to (3), m and n are the indices of shipping mode and shipment record, $COST_{truck.n}$ and $COST_{rail.n}$ are shipping costs of truck and rail, $TIME_n$ is the highway travel time between origin and destination,

Table 4. Explanatory variables of mode choice models.

Variable	Description	Average (standard deviation) in			
		Basic raw metals	Minerals	Construction	Petroleum
MODE	1: Shipped by rail 0: Shipped by truck	0.014 (0.118)	0.146 (0.353)	0.005 (0.074)	0.035 (0.183)
WEIGHT	Weight of shipment (ton)	20.2 (6.5)	28.3 (21.2)	16.7 (7.1)	20.8 (7.9)
$COST_T$	Shipping cost by truck (million rials)	4.33 (2.47)	4.97 (4.71)	2.12 (1.75)	2.22 (2.21)
$COST_R$	Shipping cost by rail (million rials)	8.74 (3.06)	10.83 (4.50)	7.53 (1.61)	6.28 (3.85)
$DIST_T$	Highway distance between origin and destination (km)	526.8 (366.4)	566.8 (411.5)	304.9 (309.8)	323.4 (326.9)
$TIME_T$	Shipping time by truck (min)	392.9 (273.4)	442.2 (323.0)	231.5 (229.2)	244.7 (242.6)
$ACCESS_O$	Access time to rail in origin (min)	33.6 (57.8)	23.6 (40.3)	50.6 (64.6)	45.6 (84.1)
$ACCESS_D$	Access time to rail in destination (min)	33.7 (66.7)	17.6 (42.7)	70.0 (90.9)	81.0 (100.1)
GCD	Great circle distance (km)	391.1 (278.9)	410.5 (294.4)	228.1 (237.4)	243.1 (249.9)
EMP_O	Industrial Employment in origin	49552 (79548)	10459 (24870)	24164 (48801)	44024 (65169)
EMP_D	Industrial employment in destination	79316 (103147)	24688 (31404)	41095 (76110)	19167 (39032)

$WEIGHT_n$ is the weight of shipment, and $ACCESS_{o,n}$ and $ACCESS_{D,n}$ represent access time to rail in the origin and destination. Descriptions of the variables and the estimated coefficients are presented in Tables 4 and 5, respectively. Google Map tools were employed to estimate highway travel time. The average travel time of all the suggested routes between origin and destination was considered for this purpose.

$$U_{R-T} = \beta_{Constant} + \beta_C\left(COST_R - COST_T\right) + \beta_{TW}\left(TIME_T \times WEIGHT\right) + \beta_{AO}.ACCESS_O + \beta_{AD}.ACCESS_D, \quad (1)$$

$$P_{Truck} = \frac{1}{1+e^{U_{R-T}}}, \quad (2)$$

$$LL(\beta) = \sum_n \sum_m y_{nm} \ln(P_n(m)), \quad (3)$$

$y_{nm} = 1$ If observation n chose m and

0 otherwise.

Akaike and McFadden's likelihood ratio index values are among the many goodness-of-fit measures that are proposed for these models and are used along with the chi-squared values of the model selection [16]. Standard t-statistics, shown in Table 5, are verified if the coefficient's effect on the choice probability is significant. Every estimated parameter in the final model is significant with a 99% confidence interval. Models have pseudo-R-squared values of more than 30% and correctly predict more than 90% of the observations. Samimi et al. [6] argued that binary models with a dominant choice (i.e., truck) inflated the percent correct values since even a constant model would correctly predict a large share of observations. Thus, the correctly predicted percentage of rare events (i.e., rail) can further validate the predictive power of the model. For minerals and petroleum commodity types, the model predicted more than 50% of rail shipments correctly. These results for basic raw metals and construction comprise 32% and 8% of rail shipments, respectively. Understandably, given that the rail market share decreases for a specific commodity type, the correctly predicted percentage of the rare event is also diminished. Choosing rail over truck could

Table 5. Binary mode choice model.

Variable	Basic raw metals		Minerals		Construction		Petroleum	
	Coefficient (*t*-value)	Elasticity	Coefficient (*t*-value)	Elasticity	Coefficient (*t*-value)	Elasticity	Coefficient (*t*-value)	Elasticity
CONSTANT ($\beta_{Constant}$)	–1.9217 (–60.5)	N.A.	–1.4322 (–111.6)	N.A.	–1.3698 (–39.5)	N.A.	–3.0837 (–108.5)	N.A.
COST (β_C)	–92.13 (–125.5)	2.08%	–29.71 (–160.6)	17.79%	–68.25 (–107.4)	0.75%	–29.77 (–59.5)	6.48%
*WEIGHT** $TIME_T$ (β_{TW})	1.308E-04 (92.2)	–2.97%	1.208E-04 (289.0)	–48.45%	2.305E-05 (12.9)	–0.13%	2.833E-04 (151.6)	–22.82%
$ACCESS_O$ (β_{OA})	–0.018 (–27.2)	0.19%	–0.072 (–76.2)	5.11%	–0.02237 (–39.2)	0.12%	–0.3775 (–52.7)	3.52%
$ACCESS_D$ (β_{DA})	–0.032 (–28.7)	0.22%	–0.008 (–34.3)	0.86%	–0.02293 (–48.1)	0.11%	–0.03669 (–33.1)	0.56%
No. of observations	676,948		662,511		2,272,797		577,497	
Log likelihood	–29677.03		–168686.17		–54136.57		–30243.9	
Chi-squared	41387.16		214075.49		46068.3		113922.57	
Pseudo R-squared	0.429		0.489		0.306		0.687	
Percent correct	98.9		92.1		99.5		97.6	
Rail percent correct	31.7		50.6		8.0		51.1	

be considered as a rare event with only 36, 17, 3, and 2% chances of occurrence for minerals, petroleum, basic raw materials, and construction commodity types, respectively. Significant variables of the mode choice model along with fitness indices and t-statistics with regard to the four types of commodity are given in Table 5.

Table 5 reveals that transportation costs, interaction of the weights by distance, and access to railway can justify the choice of freight forwarders to transport their goods. The cost coefficient of mineral commodities has high elasticity and it substantially influences the choice. This goes along with mineral commodities, being likely to be transported in large masses, and for which rail is more economical than the road.

The concurrent effect of weight and distance on the mode choice is the reason why shipment weight by highway travel time is preferred. The negative elasticity value of this variable indicates that as the ton-km of the freight increases, the probability of opting for road transportation is reduced. For instance, large shipments are more likely to be delivered via rail in long hauls. Such decisions might be the result of the fixed primary cost in the rail sector, which can be time consuming [6,17]. Considering the high elasticity of this variable in mineral and petroleum commodities, it has a substantial role in choosing the mode of transportation.

To observe the effect of railway accessibility on the mode choice, the travel time between origin/destination and the nearest railway station was measured. An increase in rail access leads to a reduction in this variable. Regarding the negative value of this variable, railway accessibility can reduce the probability of selecting truck. However, the relatively lower elasticity is indicative of its lower effect than the previous variables. Moreover, increasing accessibility in origin has a greater effect than that in destination for mineral and petroleum commodities. The effect of employees working in the industrial sector in the origin and destination was not significant on mode choice and was thus eliminated from the model.

4. Policy analysis

This section employs the proposed model to evaluate a range of pro-environment policies targeting fuel price and access to rail. Due to the 2011 report of Iran's macroeconomic statistical indicators [18,19] on air pollution and fuel consumption in rail and road sectors, adopting policies to shift from truck toward rail could greatly benefit the economics of the system. The scenarios proposed in this section are a product of gradual reduction of oil subsidy, allowing discounts on rail costs and increasing the accessibility to rail. Impacts of these scenarios on shifting freight to the intermodal mode are analyzed based on the mode choice model developed in the previous section. Eliminating subsidies and allowing discounts reflect the cost variables of the mode choice model and increase in accessibility affects both accessibility and cost variables.

To perform the cost-benefit analysis of scenarios, each unit of transportation service used (ton-km of freight) was assigned a price, reflecting its external costs imposed on society of the service. By rating these costs, some assumptions were made based on Iran's macroeconomic statistics. According to the Energy Balance Sheet and the Statistical Book of Maintenance and Railway Organizations in 2011 [20], gasoline consumption in the road and rail sectors were 0.0892 and 0.0095 liters per ton-km, respectively, considering the empty vehicle flow in the road sector. Air pollution costs generated by freight were taken into account for NO_x, SO_x, CO, CO_2, CH_4, SMP, and N_2O. The amount of air pollution in terms of the equivalent CO_2 expense in commodity movement was 1206 and 127 grams per ton-km in road and rail sectors, respectively. According to the energy balance sheet [2], the social cost of each ton of carbon dioxide was 80,000 Rials in 2002, scaling to 290,000 Rials (18.1 Dollars) in 2011 following the rate of Iran's inflation in 2002–2011. Each U.S. dollar was evaluated at 16,000 Rials based on Transportation Energy Balance Sheet [20]. Transportation cost associated with fuel consumption was estimated at 14% in the road and 4% in the rail sector considering a share of 70% and 45% for truck and rail empty vehicles, respectively. Moreover, 20% of the transportation cost was allocated to loading and unloading upon shifting the choice of vehicle from truck to rail. This share accounts for the expenses paid by the system in the analysis of scenarios. The construction cost of each railway kilometer was assumed 2 million dollars. Subsequently, based on the Strategic Railway Map [21], the completion of rail tracks under construction (Phase I) costed 3.4 billion dollars and those officially approved (Phase II) costed 6.8 billion dollars.

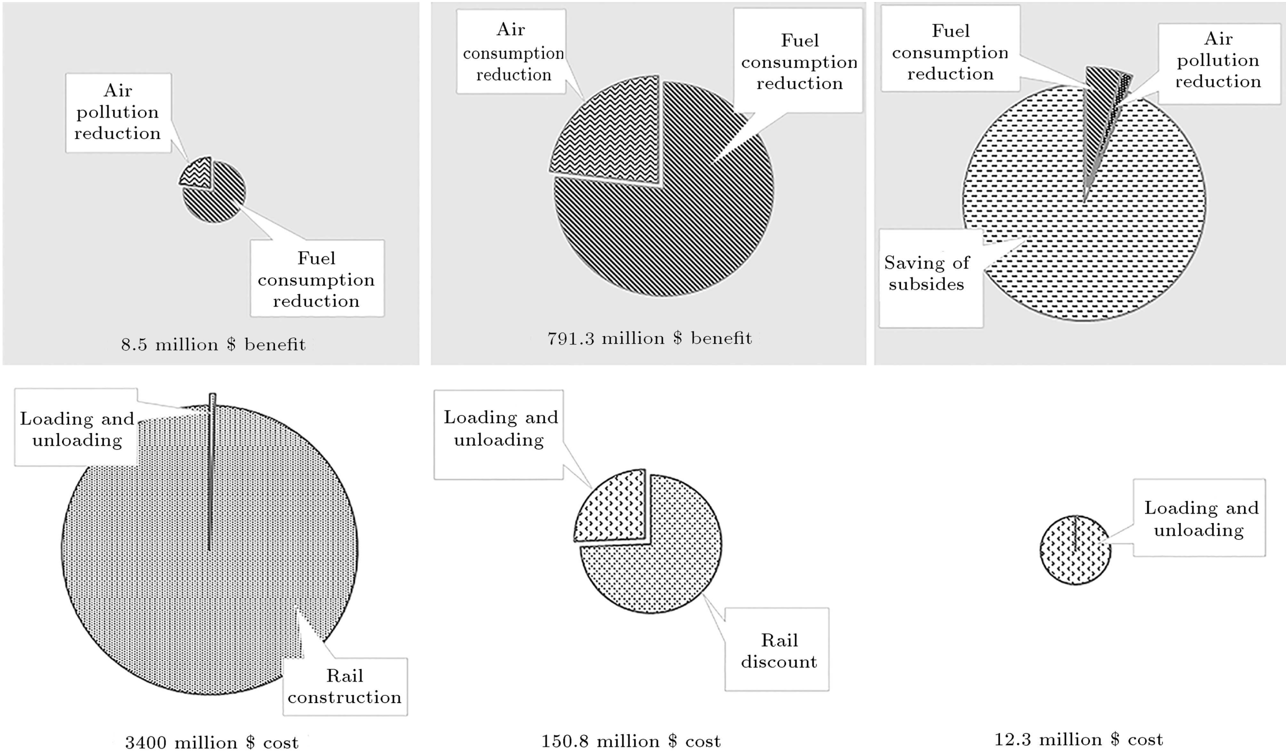
The cost-benefit analysis of scenarios was carried out to determine the dollar value of the expenses of freight shipment. The system's profit was gained from limiting the paid subsidies, the cutback of fuel consumption, and the corresponding reduction in air pollution. The system's expenses were originated from the discounts allowed on rail transportation, and the loading-unloading charges were imposed while switching from road to rail. To comprehend the significance of profits and costs better, one should note that the net income of the 2011 commodity movements in road and rail sectors was 171 and 363 million dollars, respectively [19,20].

Analyzing the proposed policies individually is an attempt to reveal which of the three policies of subsidy reduction, railway discounts, and increased accessibility contributes to the greatest benefit to the system. According to the results, allowing higher discounts is more effective in encouraging senders to use rail (see Figure 3). Analysis indicated that allowing discounts was 3 to 4 times more effective than reducing subsidies in shifting to the intermodal transport; nevertheless, the earnings made out of reducing the paid subsidy were considerable. As Figure 3 indicates, for a 30% decrease in subsidy, the system gains 198.3-million-dollar benefit from shifting to the intermodal transport, in addition to 3377-million-dollar profit from the subsidy reduction. This is compared to the 640 million dollars net benefit gained from 30% discount on rail costs. Once compound policies of reducing subsidies and allowing discounts were analyzed, results showed that a combination of the two policies increased the system's profit in the non-linear manner. Finally, increasing railway accessibility improved the average benefit of scenarios by 7% after Phase I and 13% after Phase II.

Scenarios of increasing accessibility while allowing discounts are hardly feasible financially. Moreover, adding rail access to the subsidy reduction scenario had insignificant effect on shifting to rail mode, while no discounts were offered. However, once these scenarios were joined by allowing discounts, the role of increasing the accessibility became considerably substantial. According to the results, the greater discount can enhance the effect of accessibility up to 6% of the average benefit. Total saving is defined based on the total profits (including a reduction in fuel consumption, air pollution, and subsidies) and total costs (including rail discount, loading and unloading, and railway construction).

In Figure 4, line styles present a fixed percentage of subsidy removal, while the similar shapes intend the same extent of rail discount. It shows that rail discount shifts the result further on the environmental axis, whereas decreasing subsidy has a higher impact on total saving. The results also show that the response to the offered discount is not linear. For instance, in the case of policies involving cutting the fuel subsidy by 20%, a 1% increase in rail discount led to a net benefit of 19.5 and 26.5 million dollars in the 0–15% and 15–30% range, respectively.

Scenarios with contrasting values in offering rail discount and removing subsidy were analyzed based on the current rail accessibility to clarify the difference in the effect of scenarios on types of commodity, as shown



(a) Increased rail* (b) 30% rail discount (c) 30% subsidy

*Phase one completion

Figure 3. Cost-benefit analysis of distinct policies.

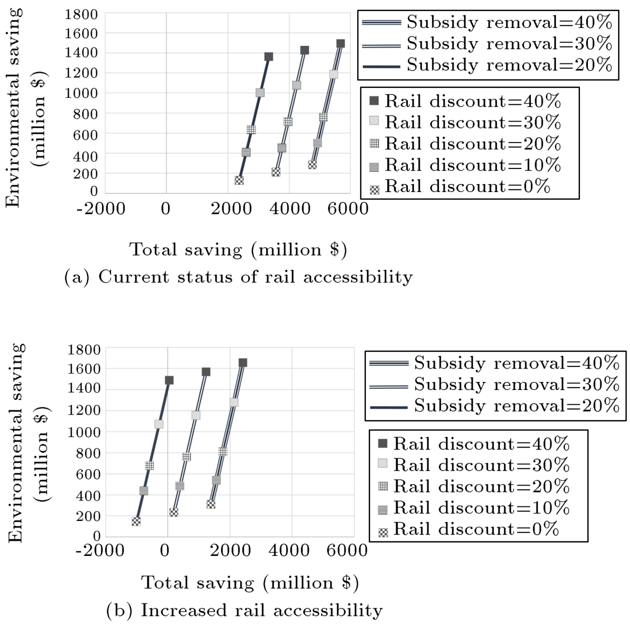


Figure 4. Compound scenarios of rail discount and gasoline subsidy reduction.

in Figure 5. It is observed that the greater proportions of the benefits are linked to raw metal and mineral goods. The analysis showed that allowing rail discounts had a great impact on the vehicle choice mode of raw metal and mineral goods, while reduction of subsidies had the greatest impact on raw metal and construction goods. The average shares of raw material, mineral, construction, and petroleum goods in the profit gained by removing the subsidies were 24, 25, 38, and 13%, respectively. Table 6 illustrates the effects of applying subsidy removal and rail discount of up to 40% at a 10% interval, besides two statuses of rail accessibilities.

5. Summary and conclusions

A great proportion of commodity transaction is based on the truck mode in Iran despite the fact that fuel consumption and air pollution are considerably lower in the rail sector. Policy-sensitive scenarios to shift modal decisions were analyzed, and their potential profit of the system was evaluated. The disaggregate freight data containing more than 155 thousand rail and 8.7 million truck shipment records were used to develop the model. Mode choice models were estimated for four types of goods (namely raw metals, minerals, construction, and petroleum) that accounted for almost 56% of the total ton-km freight movements in Iran.

The significant variables of the mode choice model included transportation cost, weight times distance,

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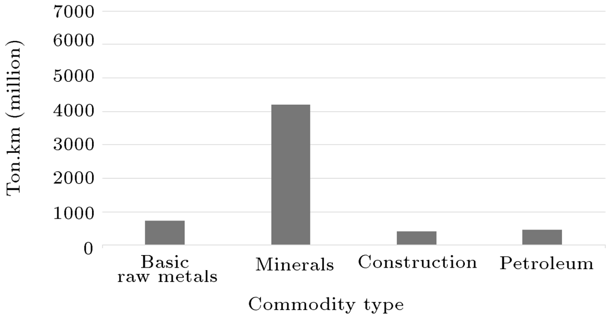
Table 6. Cost-benefit analysis of scenarios.

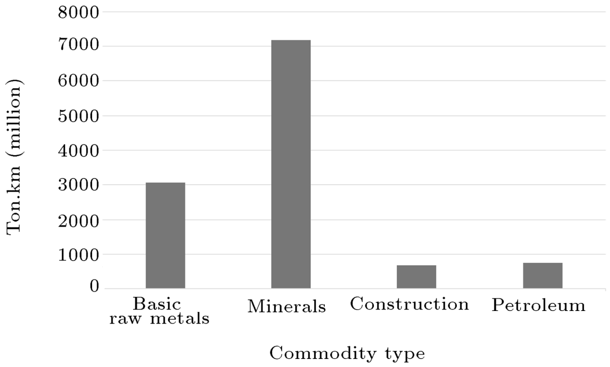
Scenario				Profits (million $)				Costs (million $)			Scenario results	
Scenario number	**Accessibility***	**Subside removal (%)**	**Rail discount (%)**	**Reduction in consumption of fuel**	**Reduction in air pollution**	**Reduction in subsides**	**Environmental profit** (%)**	**Rail discount**	**Loading and unloading**	**Railway construction**	**Total saving (million $)**	**Shift to intermodal (%)**
1	**1**	**0**	**0**	6.58	2.0	0	100	0	0.58	3400	**–3392.0**	0.1
2	**1**	**20**	**0**	111.1	33.6	2252	6.0	0	8.31	3400	**–1011.9**	2.4
3			**20**	518.9	157.0	2252	23.1	79.6	37.53	3400	**–589.7**	13.3
4			**30**	821.4	248.5	2252	32.2	140.6	60.84	3400	**–280.0**	23.8
5			**40**	1142	345.6	2252	39.8	206.9	85.53	3400	**46.8**	34.9
6	**1**	**30**	**0**	177.4	53.7	3377	6.4	0	13.87	3400	**194.6**	4.0
7			**20**	584.8	176.9	3377	18.4	86.7	44.77	3400	**607.7**	15.4
8			**30**	886.5	268.2	3377	25.5	150.9	69.42	3400	**911.9**	26.0
9			**40**	1204	364.3	3377	31.7	219.2	95.14	3400	**1231.5**	37.2
10	**1**	**40**	**0**	236.2	71.5	4503	6.4	0	19.34	3400	**1391.6**	5.4
11			**20**	622.2	188.3	4503	15.3	91.4	50.37	3400	**1771.9**	16.7
12			**30**	980.3	296.6	4503	22.1	165.5	80.94	3400	**2133.8**	29.2
13			**40**	1270	384.4	4503	26.9	232.5	105.6	3400	**2419.8**	39.6
14	**0**	**0**	20	377.7	114.3	0	100.0	66.4	23.74	0	**401.9**	9.7
15			**30**	607.5	183.8	0	100.0	112.0	38.72	0	**640.6**	16.6
16			**40**	937.4	283.6	0	100.0	173.6	61.96	0	**985.5**	28.6
17	**0**	**20**	**0**	99.65	30.1	2252	5.5	0	7.14	0	**2374.3**	2.2
18			**20**	485.3	146.8	2252	21.9	77.25	34.58	0	**2771.9**	12.7
19			**30**	768.8	232.6	2252	30.8	135	56.34	0	**3061.3**	22.6
20			**40**	1045	316.2	2252	37.7	195	77.7	0	**3340.1**	32.5
21	**0**	**30**	**0**	161.6	48.9	3377	5.9	0	12.2	0	**3575.6**	3.7
22			**20**	547.3	165.6	3377	17.4	83.97	41.3	0	**3965.0**	14.7
23			**30**	825.9	249.9	3377	24.2	144.	64	0	**4244.5**	24.6
24			**40**	1093	330.8	3377	29.7	205.	85.8	0	**4510.6**	34.2
25	**0**	**40**	**0**	216.8	65.6	4503	5.9	0	17.3	0	**4768.3**	5.1
26			**20**	582.0	176.1	4503	14.4	88.3	46.45	0	**5126.5**	15.9
27			**30**	910.7	275.5	4503	20.9	158	74.5	0	**5456.8**	27.6
28			**40**	1146	346.8	4503	24.9	216	94.6	0	**5685.2**	36.2

*: Accessibility status 1 refers to development and operation of railways which are under construction and phase one of strategic map of railway department;

**: Environmental profit: share of fuel and air pollution in total profits.



(a) Subsidy removal=30%, rail discount=10%



(b) Subsidy removal=10%, rail discount=30%

Figure 5. Effect of rail discount and subsidy removal on ton-km of shifted goods by commodity type.

and the distance to the nearest railway station. Mode choice model was applied to investigating the policies of gasoline subsidy reduction, allowing discounts on the rail transportation costs, and increasing accessibility to the railway network. Accordingly, allowing discounts had the greatest impact on changing the transportation mode and removing the subsidies led to substantial profit. Air pollution response of these scenarios was studied, results of which suggested that in the compound scenarios, the profit earned from reducing air pollution started from half of the income of road commodity movement and arriving up to 1.5 of this income. Moreover, by removing 30% of subsidy, allowing 40% of rail discount, and completing the railway tracks under construction (Scenario 9 in Table 6), the scenario can extend to the further reduction of air pollution; in addition, earning the final profit (1231.5 million dollars) represents 2.3 times the sum of the country's transportation income from the rail and road sectors (534 million dollars). As argued above, initial studies have indicated the existence of potential profit in the modal shift from truck to rail, and more comprehensive studies can pursue improved functional applications. As argued in this research, initial studies have indicated the existence of potential profit in the modal shift from truck to rail by using the scenarios above; thus, more comprehensive studies should pursue improved functional applications.

The findings of this paper can be used to:

- Consider potential policies that could shift freight from road to rail;
- Estimate environmental benefits of the proposed scenarios;
- Introduce a platform to model cost-efficient and policy-sensitive freight choice models with public data, particularly in developing countries with limited research budgets.

The following research venues are also recommended to expand this research:

- Safety benefits should be considered in the scenario analysis, in addition to fuel consumption and air pollution. Many safety studies have understandably acclaimed that share of trucks in roads contributes to severity and frequency of accidents. Thus, a significant safety improvement is expected if freight movements are shifted from truck to rail;
- Truck mode should be further classified (e.g., full-truckload, and less-than-truckload) and then, a generalized extreme value model may be applied;
- Other than rail access development, scenarios that improve reliability and flexibility of rail should be considered;
- More advanced shipping cost models should be calibrated and validated.

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Appendix

Commodity classification bridge to SCTG codes is shown in Table A.1.

Table A.1. Commodity classification.

Code	Name	Description	SCGT code
1	Agriculture	Agricultural products except for animal feed	3
2	Else	Cereal grains	2
3	Else	Meat, fish, and seafood, and their preparations; milled grain products and preparations, and bakery products; other prepared foodstuffs, and fats and oils; Alcoholic beverages; tobacco products	5, 6, 7, 8, and 9
4	Else	Animals and fish; animal feed and products of animal origin	1 and 4
5	Metal equipment	Articles of base metal	33
6	Basic raw metals	Base metal in primary or semi-finished forms and in finished basic shapes	32
7	Minerals	Nonmetallic minerals; metallic ores and concentrates; coal	13, 14, and 15

Table A.1. Commodity classification (continued).

Code	Name	Description	SCGT code
8	Construction products	Monumental or building stone; natural sands; Gravel and crushed stone; nonmetallic mineral products	10, 11, 12, and 31
9	Else	Electronic and other electrical equipment and components and office equipment; furniture, mattresses and mattress supports, lamps, lighting fittings	35 and 39
10	Else	Precision instruments and apparatus	38
11	Else	Printed products; miscellaneous manufactured products	29 and 40
12	Vehicle, machinery	Machinery; motorized and other vehicles; transportation equipment	34, 36, and 37
13	Else	Plastics and rubber	24
14	Fertilizer	Fertilizers	22
15	Else	Pharmaceutical products	21
16	Else	Chemical products and preparations	23
17	Else	Basic chemicals	20
18	Petroleum compounds	Crude petroleum; gasoline and aviation turbine fuel; fuel oils; coal and petroleum products	16, 17, 18, and 19
19	Else	Logs and other wood in the rough; wood products	25 and 26
20	Else	Pulp, newsprint, paper, and paperboard; paper or paperboard articles	27 and 28
21	Else	Textiles, leather, and articles of textiles or leather	30
22	Else	Waste and scrap	41
23	Else	Mixed freight; commodity unknown	42 and 43

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