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Estimating the Marginal Productivity of Roads and Vehicles in Sri Lanka

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Abstract

Roads are a vital component of the transportation system, and Sri Lanka is experiencing rapid development in all classes of road networks. The introduction of expressways has been one of the recent additions to Sri Lanka's road network. The Road Development Authority has plans to extend highways to cover the entire island in the near future. Road networks play a significant role in national development and contribute to the overall performance and social functioning of communities. They enhance mobility, lifting people out of isolation and poverty, which explains the increasing preference for road usage due to the various benefits it offers. This study focuses on Sri Lankan highways, particularly three types: A class, B class, and E class. The research aims to estimate the marginal productivity of roads in Sri Lanka while considering provincial GDP, vehicle stock, and road stock. Additionally, the study aims to identify the long-term responses of GDP to potential increments. Specifically, the selected A and B class roads connect major districts in Sri Lanka and serve transportation needs in sectors such as agriculture, industry, and services. The study covers GDP, road stock, and vehicle stock from 2005 to 2020 across the country's nine provinces. Data for the research was collected from the Central Bank of Sri Lanka (CBSL), Road Development Authority – Sri Lanka, and Ministry of Transport and Highways – Sri Lanka, providing relevant and accurate secondary data. The collected data were analyzed against various variables to achieve the research objectives. Regression analysis was utilized to identify the relationships and estimate the impact of variables.

Furthermore, GDP values were estimated by categorizing vehicles and roads into several types. Regression analysis offers insights into how changes in variables impact the unit of GDP.

Keywords: Marginal Productivity, Highways, Road network in Sri Lanka, Gross Domestic Product.

1. Introduction

Roads serve as the primary means of connecting people in different locations, making them an integral part of human life. The connectivity provided by roads is a crucial determinant of people's well-being and quality of life. Improved accessibility through roads allows individuals to actively participate in their daily activities. When compared to other available modes of transportation, road networks are more flexible and convenient for people. Road transport vehicles can easily pick up and drop off people and goods anywhere (Agatz et al., 2012).

Throughout human civilization and technological advancements, roads have evolved from small trails to controlled access routes. The rise of international trade and the export of raw materials such as rubber, coffee, tea, and coconut has necessitated the rapid development of efficient road transport in Sri Lanka. These roads enable effective transportation to reach Sri Lanka's ports and connect to maritime transportation, the next mode of transport. In Sri Lanka, there are four major types of national highways that connect the entire island. The table below provides information on these four categories, including their total length and speed limits.

Table 1: Road Categories in Sri Lanka

Class	Description	Speed Limit (Kmph)	Total Road Length (Km)
E	High speed, High traffic corridors, which duplicate A class routes that are having difficulty coping with the traffic volume.	100	312.586
A	The national highway networks.	70	4217.42
B	Major provincial roads and used as feeder roads for A and E class roads	60	8037.981
C	Local residential Roads.	50	

Source: Road Development Authority – Sri Lanka

The improved road networks have enhanced accessibility and facilitated greater mobility. The expansion of these roads directly influences both the economic and social development of the country. This is primarily due to the connection they provide between rural communities in Sri Lanka, ensuring access to essential services such as education, healthcare, and markets.

In Sri Lanka, there are four major types of national highways that connect the entire island, ensuring comprehensive road connectivity. As the demand for transportation continues to increase, people in Sri Lanka show a strong preference for using roads for their daily trips, even though the Sri Lankan Railway service is available. This preference can be attributed to the high accessibility and flexibility offered by roadway networks. However, this has also resulted in high levels of congestion on national highways, indicating the need for efficient management and infrastructure planning to alleviate congestion issues.

In recent years, Sri Lanka has made significant advancements in its road transport system through the construction of an expressway network. This strategic development comprises various expressway projects that are in different stages, including under construction, planning, and already in use. The following table provides details of some of the expressways in Sri Lanka.

Table 2: Road Categories in Sri Lanka

Number	Name	Length (km)	Northern end	Southern end	Completed
E01	Southern Expressway	200.45	Kadawatha, Colombo	Mattala	2020
E02	Outer Circular Expressway	28.8	Kerawalapitiya	Kottawa, Colombo	2019
E03	Colombo-Katunayake Expressway	25.8	Bandaranaike International Airport	New Kelani Bridge, Colombo	2013
E04	Central Expressway (Section II)	40.9	Kurunegala	Mirigama	2022
E04	Central Expressway (Section I, III & IV)	137.1	Dambulla	Kadawatha	Under construction
E06	Magampura Expressway	16.5	Andarawewa	Hambantota	2019
E09	Port Access Elevated Highway	5.3	New Kelani Bridge, Colombo	Port city	Under construction
	Ruwanpura Expressway	73.9	Kahathuduwa	Pelmadulla	Under construction
	NKB-Athurugiriya Elevated Highway	17.3	New Kelani Bridge, Colombo	Athurugiriya	Under construction

The E01 Southern Expressway is Sri Lanka's inaugural expressway network. The planning phase for this road network commenced in 1990, followed by construction activities that began in 2003. The Southern Expressway serves as a vital link connecting two significant regions within Sri Lanka. While it is important to note that these expressways are not intended for bicycle use, motorcycles, and three-wheelers. they have nonetheless brought numerous benefits to the country.

The marginal productivity of roads is influenced by the demand for transportation and the choices people make regarding road usage (Lindsney* & Verhoef*, 2001). In Sri Lanka, there is a growing preference for using roads for daily trips, even with the existence of the Sri Lankan Railway service. This increased road usage has led to high congestion on national highways and an increase in highway accidents, resulting in various negative effects on the country. The occurrence of road accidents is greatly influenced by driver behavior, which is closely linked to their socio-economic characteristics, including gender, age, income level, educational background, and marital status (Shaja, M.M.M., and Bandara Y.M., 2021). As a result, the development and maintenance of roads have become vital concerns. In response to this, the construction of expressways has commenced in Sri Lanka.

The marginal productivity of roads varies between highways and expressways due to significant differences in demand. Unlike highways, expressways in Sri Lanka restrict the types of vehicles allowed to enter the network. Additionally, the Road Development Authority, responsible for maintaining the expressways, imposes charges on vehicles using these networks, with varying prices during the day and night. As a result, the demand for the expressway is subject to fluctuations based on these pricing changes.

Factors affecting the demand for the Outer Circular Highway (OCH), for instance, include the population of cities like Colombo and Gampaha, employment rates, income levels, tourism, commercial and educational institutions, land use patterns, parking facilities, and fuel prices. Tourism, for example, may influence the seasonal demand for the expressway, while the presence of educational institutions in cities affects its demand as well. These variables can have varying short-term and long-term impacts on how people respond to changes.

Changes in the aforementioned factors result in variations in demand. For instance, an increase in expressway prices may lead to a decrease in demand, while an increase in income levels may result in increased usage (Dougles B, & Lee J., 2000). Understanding these variations provides insights into the elasticity of the expressway concerning different factors. By obtaining numerical values for elasticity, it becomes possible to plan a better transportation system for the expressway. The current pricing system has excluded certain segments of society, as individuals with lower incomes may need to spend a significant portion of their salary on public transport via the expressway, while those with higher incomes pay less for their private vehicles. This makes it unaffordable for lower-income individuals. Consequently, these values are valuable for planning future expressway constructions.

The findings of this research can help predict various trends, policies, and projections that impact transportation activities. For example, with increasing congestion in cities, the efficient utilization of road infrastructure becomes increasingly important. Having knowledge of elasticities is vital for authorities to evaluate alternative management policies for freeway demand, aiming to enhance social welfare and the level of service for highway users. These findings can also contribute to identifying suitable improvement solutions, implementing transport demand management, informing policy-making processes, and enhancing overall transport system implementation.

The following are the research objectives of this paper,

- Determine the factors that impact the marginal productivity of roads.
- Investigate the relationship between road stocks, vehicle stocks, and the estimation of marginal productivity of roads.
- Identify the correlation between GDP growth and changes in road stock and vehicle stock elasticity.

2. Literature Review

Various studies have been carried out regarding travel demand and elasticity, encompassing diverse aspects such as definitions, factors influencing travel demand, demand calculation, and equations. However, limited research specifically focused on Sri Lanka's context due to the relatively recent introduction of expressways to the country's road network.

2.1. What is marginal productivity?

The marginal productivity of roads refers to the change in output resulting from a change in the road capital stock by one unit (one kilometer) (Stiven et al., 2016). Despite the availability of various modes of transportation, road infrastructures are widely utilized by a significant number of commuters. These commuters can be categorized into two groups: those traveling for personal reasons and those involved in freight transportation. Personal travel purposes include education, business, commerce, culture, and social activities. Freight transportation purposes include timely delivery of goods, machine and vehicle transfers for sales, and milk-run transportation. The economy of Sri Lanka heavily relies on private sector production. This research aims to develop a method for measuring the marginal productivity of roads. The construction of roads directly contributes to increasing GDP as an investment in the national economy, while also generating multiplier effects across other sectors. Thus, the development of roads indirectly contributes to GDP growth. Road productivity is calculated by dividing the total output per period by the total road stock utilized during that period. Productivity serves as a crucial factor in determining operational efficiency (Jiwattanakupaisarn, Noland, & Graham, 2012).

2.2. Factors affecting the marginal productivity of roads.

The productivity of a roadway network is influenced by various factors, including the vehicle stock of Sri Lanka and the road stock of Sri Lanka. These factors can affect different types of travel in distinct ways, as indicated by research conducted by Todd Litman in 2017:

- Commercial (business) travel is generally less sensitive to changes than personal travel.
- Commuter trips are typically less elastic compared to shopping or recreational trips.
- Travelers with higher incomes tend to be less price-sensitive than those with lower incomes.
- Weekday trips may exhibit different elasticities than weekend trips.
- Urban peak period trips often show price inelasticity due to congestion, as lower-value trips are discouraged, resulting in a higher proportion of higher-value automobile trips.

These findings provide insights into how different factors influence the demand and responsiveness of various types of travel within a roadway network.

2.3. Road stock of Sri Lanka

There have been numerous research studies conducted on the productivity of roads, as it plays a significant role in highway efficiency. The measurement of road infrastructure is based on the monetary value of the capital stock, determined through the perpetual inventory method. This method calculates the stock of road infrastructure in a specific year by summing the past real expenditures on roads, adjusted for depreciation (Fuente & Económico, 2010). However, empirical evidence in the literature does not distinguish between the productivity effects of construction activities and maintenance, making it challenging to derive specific policy insights.

A previous research paper's main contributions lie in providing updated estimates of the productivity effects of road investment using a dynamic model. It also evaluates the cost-effectiveness of road capacity expansions. Unlike previous research that often relies on regression coefficients, this study examines the marginal productivity of a one lane-mile increase in capacity (Melo, Graham, & Brage-Ardao, 2013). By analyzing the present value of future output gains compared to estimated costs, it determines whether investment in roads is beneficial or not. The dynamic panel specification, known as a first-order autoregressive distributed lag (ARDL) model, considers the dynamic adjustment of state output to changes in road infrastructure and other factors.

Three types of measures are distinguished: output measures, input measures, and productivity measures in this paper. Output measures are crucial for classifying the relative importance of different roads in economic activity. They provide information about the contribution of roads to economic output. Input measures are used to assess the cost of different roads, while productivity measures help evaluate the resource efficiency of roads in delivering outputs relative to input levels. These measures are useful for benchmarking road performance and assessing their efficiency in achieving desired outcomes (Stiven et al., 2016).

2.4. Vehicle stock of Sri Lanka

Vehicle stock is another important aspect to consider. According to Fay Dankerley, Charlene Rohr, and Andrew Daly (2010), changes in income directly impact the demand for transportation, influencing the number of trips taken and the distance traveled by individuals. Additionally, Bradburn and Hyman (2002) highlight that the indirect impact of GDP on car traffic, resulting from its influence on car ownership, is more significant than the direct effect.

Goodwin, Dargay, and Hanly (as cited in Todd Litman, 2007) made predictions regarding the effects of a 10% increase in real income:

- The number of vehicles and the total amount of fuel consumed by them would both rise by nearly 4% within approximately a year and over 10% in the long run.
- Traffic volume, representing total vehicle travel, would increase by about 2% within a year and 5% in the long run, indicating that the additional vehicles are driven less than the average mileage.

Furthermore, Blumberg and Pierce (as cited in Todd Litman, 2007) observed that as household income rises from low to medium levels, vehicle ownership and travel tend to increase at a faster proportionate rate than incomes.

2.4. Estimation method

Toll roads have recently been introduced to Sri Lanka's road network. There is limited literature available on the estimation of expressway productivity in the country. Research studies conducted in foreign countries have focused on their respective roadway networks, raising questions about the applicability of their models and methods to the transportation system in Sri Lanka. Furthermore, people's attitudes towards road access and the number of vehicles they own may differ, adding complexity to the analysis. Unfortunately, there is a scarcity of numerical data available for this particular study.

2.5.1. Data collection method

Piyapong Jiwattanakulpaisarn, Robert B. Noland, and Daniel J. Graham utilized data on roadway lane-mile for the forty-eight contiguous US states from 1984 to 2005. Their objective was to measure direct changes in the physical stock of highway infrastructure within each state.

Inmaculada C. Álvarez and Reyes Blázquez conducted their study using provincial Spanish panel data spanning from 1980 to 2007. They employed nonparametric frontier techniques based on Data Envelopment Analysis (DEA) to analyze the Malmquist productivity indexes. This approach allowed them to evaluate productivity growth in terms of technological changes and efficiency gains.

2.5.2. Statistical methods to calculate marginal productivity of roads.

Various statistical tests are employed to fine-tune a model to fit specific circumstances. In the context of urban regions, the Three-step models are commonly utilized to forecast highway productivity and assess the impact of expanding highway capacity (Todd Litman, 2007). The Three-step model consists of the following steps:

- Providing up-to-date estimates of the productivity effects of highway investment using a dynamic model.
- Evaluating the cost-effectiveness of highway capacity expansions based on these estimates.

Coefficients derived from regressions, which are commonly reported in previous research, do not always provide conclusive evidence regarding the cost-effectiveness of investment. To address this limitation, we determine the marginal productivity of increasing capacity by one lane-mile.

In this empirical investigation, the framework outlined by Jiwattanakulpaisarn et al. (2011) was adopted which defines a dynamic log-linear production function model. This model accounts for time lags in the productivity effect of highways.

Where α & β are model coefficient and ε_t is random error term. Moreover, in this model β is the unit and it is constant. Let, P_1, P_2 & Q_1 & Q_2 are two observations, and above log-log model written in this form,

$$\ln(Q_1) = \alpha + \beta \ln(P_1) + \varepsilon_t \qquad (1)$$

$$\ln(Q_2) = \alpha + \beta \ln(P_2) + \varepsilon_t \qquad (2)$$

(1) – (2) $$\ln(Q_1) - \ln(Q_2) = \beta \ln(P_1) - \ln(P_2)$$

$$\beta = \frac{\ln(Q_1) - \ln(Q_2)}{\ln(P_1) - \ln(P_2)}$$

Multiple models and equations are available for calculating productivity. In their study, Louis de Grange, Felipe Gonzalez, and Rodrigo Troncoso (2015) utilized log linear regression models with aggregated data to estimate the productivity of three distinct urban freeways in Santiago. They also highlighted three main econometric models commonly used for productivity estimation:

- Linear (or log-linear) regression using cross-sectional data.
- Linear (or log-linear) regression using time series data.
- Linear (or log-linear) regression using panel data.

These models provide different approaches to analyzing and estimating productivity in various contexts, allowing for a comprehensive understanding of the factors influencing productivity.

2.5.3. Elasticity of road and vehicle usage.

When calculating price elasticity, it is essential to consider inflation. As stated by Todd Litman (2017), elasticity analysis should be conducted using real prices that are adjusted for inflation, rather than using nominal or current prices that are not adjusted for inflation. Goodwin, Dargay, and Hanly (as cited in Todd Litman, 2007) made predictions regarding the effects of a 10% inflation-adjusted fuel price increase:

- Traffic volumes are expected to decrease by approximately 1% within a year and 3% over the long run (five years).
- Fuel consumption is projected to decrease by about 2.5% within a year and 6% over the long run.
- Vehicle fuel economy is anticipated to improve by approximately 1.5% within a year and 4% over the long run.
- Total vehicle ownership is estimated to decrease by less than 1% in the short run and 2.5% in the long run.

2.5.4. Use of aggregated and disaggregated data.

Discrete choice models, such as logit and probability models, are typically employed when working with disaggregated data. This means that information is available at the individual level, such as data on car drivers or public transport users. Such data is often obtained through revealed or declared preference experiments, such as surveys.

When the objective is to predict future flows, using aggregate data is natural and even preferred. However, if the aim is to simulate user behavior or draw statistical inferences, disaggregated data is more suitable (Oum, 1989).

Furthermore, Labeaga and López (as cited in Louis de Grange, Felipe Gonzalez & Rodrigo Troncoso, 2015) highlight that the choice of econometric model and technique depends on the type of data available, whether it is cross-sectional, time series, or panel data. The selection of the appropriate model and technique should align with the characteristics of the data at hand.

2.5.5. Models developed by researchers from other countries.

In a study by Piotr S. Olszewski and Litian Xie (2002), a price elasticity analysis was carried out for the road sector in Singapore. To conduct this analysis, the model proposed by Polak et al. (1994) was utilized. This model establishes the relationship between traffic flows and various factors including travel cost, income, car stock, and other explanatory variables.

$$\ln(Q_t) = \beta_0 + \sum_i \beta_i \ln(X_{it}) + \beta_Q \ln(Q_{t-1}) + \varepsilon_t$$

Where,

$Q_t = Traffic\ flow$

$X_t = Vector\ of\ explanatory\ variables\ in\ year\ t$

$\beta = Vector\ of\ model\ coefficient$

$\varepsilon_t = Disturbance\ term\ (Possibly\ serialy\ correlated)$

This model has two important benefits, log-log formulation means that each coefficient β_i has a direct interpretation as the short term elasticity (E_{st}) of flow with respect to variable X_i. Secondly, the geometric lag structure which is implicit in the use of the lagged dependent variable Q_{t-1} provides a plausible characterisation of adjustment dynamics, leading to the following estimate of long term elasticity (E_{Lt}) (Piotr S Olszewski & Litian Xie, 2002).

$$(E_{Lt}) = \frac{\beta_i}{1 - \beta_0}$$

Furthermore, the authors calculated the time-variable elasticity by dividing the time periods into specific segments. These segments include the saturation toll period, which ranges from 7:30 am to 8:30 am and 6:30 pm to 7:30 pm. The high toll period encompasses 8:30 am to 9:30 am, 6:00 pm to 6:30 pm, and 7:30 pm to 9:00 pm (which corresponds to the peak-hour toll for most segments). The remaining hours are categorized under the base toll period.

In their estimation model, the authors considered various factors that influence the traffic volume on the Santiago freeways. These factors include toll charges, fuel prices, seasonal variables, and controls that reflect the level of activity within the city.

And the model they used is,

$$\ln(flow_{it}) = \alpha + \eta_f \ln(toll_{it}) + \eta_g \ln(fuel_t) + \eta_{UOCT} \ln(UOCT_t) + \gamma' D + u_{it}$$

Where,

$i = freeway\ toll\ palza\ index$

$t = time$

$\eta_f, \eta_g = free\ way\ toll\ and\ fuel\ price\ elasticities\ respectivley$

$\gamma' D = dichotomous\ variable\ sets\ for\ time\ of\ day, day\ of\ the\ week, month\ \&\ year$

$UOCT = Total\ flow\ of\ four\ toll\ free\ arterial\ roads\ in\ the\ city$

Furthermore, the authors reached the conclusion that drivers in Santiago are more sensitive to changes in fuel prices compared to changes in toll charges. This is supported by their finding that the fuel price elasticity was higher than the toll elasticities. This suggests that individuals in Santiago are highly inclined to reduce their travel time.

In a separate study conducted by Mico Mrkaic and Rado Pezdir (2008) in Slovenia, toll and fuel elasticities for cars and trucks passing through a toll station were examined using high-frequency data collected over a period of four years. The use of high-frequency data provides several advantages, including an increase in the power of hypothesis tests with a larger number of observations and the ability to analyze the temporal microstructure of demand for highway transport. By analyzing the collected data from the toll station, the authors identified several facts regarding travel demand and traffic volume trends. These facts include a strong seasonal dependency, a significant dependency on the day of the week, and an overall increasing trend in traffic volume driven by economic growth.

Based on these findings, the authors concluded that any econometric models should incorporate dummy variables to account for seasonal cycles, trend variables, weekday dummies, and time dummies. However, there were certain limitations in their study as they did not consider certain factors that could influence the model, such as the number of daily immigrants, available alternatives to the toll road, employment levels in the cities, and the nationality of the drivers.

And the model they developed to estimate the elasticities is,

$$\ln(q_t) = \sum_{i=1}^{k} a_i * \ln(q_{t-i}) + b\ln(p_t) + c\ln\left(p_t^g\right) + d\ln\left(p_t^d\right) + eD_d + fD_m + gt + \varepsilon_t,,$$

Where,

$q_t = Number\ of\ cars\ passing\ toll\ station\ at\ time\ t$

$p_t = Tol\ at\ time\ t$

$D_d = Dummy\ variable\ for\ week\ day$

$D_m = Dummy\ variable\ for\ month$

$P^d = Real\ price\ of\ D - 2\ diesel\ fuel$

$P^g = Real\ price\ of\ 95\ octane\ unleaded\ gasoline$

$t = time\ trend$

$\varepsilon_t = stochastic\ disturbance$

$a_1, a_2, \dots \dots \dots a_k, b, c, d, e, f, g\ are\ parameters\ to\ be\ to\ be\ estimated.$

Short run price elasticity of demand is,

$$E_{p,short,s}^{demand} = b$$

Long run toll elasticity is demand,

$$E_{p,short,s}^{demand} = \frac{1}{1-(a_1+a_2+\ \dots .a_k)}$$

Based on their findings, the researchers reached the conclusion that users of Slovenian toll roads generally exhibit low price sensitivity. However, they were unable to draw definitive conclusions regarding fuel price elasticity due to a lack of detailed data on the vehicle ownership structure within the country. It should be noted that vehicles from neighboring countries also enter the toll road and use it. As a result, changes in fuel prices within Slovenia may not have a significant impact on these users since they may prefer to fill their tanks in their own country.

3. Methodology

The primary goal of this research is to estimate the marginal productivity of highways in Sri Lanka. To accomplish this, several specific objectives have been established. Firstly, an extensive literature review was conducted to identify all the factors that influence the marginal productivity of roads. From this comprehensive analysis, the road stock and vehicle stock of Sri Lanka were identified as the two major factors affecting productivity. Subsequently, the current road stock and vehicle stock data of Sri Lanka were collected at the provincial level, spanning from 2005 to 2020. These data were then organized into different datasets to facilitate the estimation process. In order to achieve the research objectives, an expressway methodology was employed, utilizing the collected stacked data. Regression analysis was the chosen method for this study.

3.1. Data Collection

In Sri Lanka, the economy is significantly impacted by roads and vehicles. To investigate the factors influencing the marginal productivity of vehicles and roads, three types of secondary quantitative data were collected from CBSL, namely GDP, vehicle stock, and road stock of Sri Lanka. To ensure an effective estimation method, the data were organized by province for a period of 15 years from 2005 to 2020. Sri Lanka has nine provinces, and the major road types, categorized as A, B, and E, are observed. Additionally, vehicles were classified into eight categories, including omnibuses, private coaches, dual-purpose vehicles, private cars, land vehicles, goods transport vehicles, motorcycles and three-wheelers, and others. These vehicle types serve various purposes in the agriculture, industry, and services sectors. The data collection format is provided below,

Table 3: Sample data of vehicles from 2005 to 2020

VSK Western								
VSK Western	Omnibuses	Private Coaches	Dual Purpose Vehicles	Private Cars	Land Vehicles	Goods Transport Vehicles	Motor Cycles & Threewheelers	Others
564,497	7028	9296	81720	110799	11827	55836	276277	11714
614,366	6703	8881	85794	116,990	12,532	67,428	307,449	8589
682,940	7774	9229	91835	131128	12575	62381	355368	12650
794,832	8105	11360	99469	146909	14700	82405	430767	1117
886,243	8421	11678	102821	166223	15455	78609	503035	1
967,097	7124	12096	106571	182421	16793	83891	556329	1872
972,787	6493	11290	102613	183687	14969	82254	569507	1974
969,337	6419	10925	100840	182078	14396	81767	571109	1803
1,075,099	6916	12090	105831	200986	88570	15404	643559	1743
1,204,099	7778	12696	116467	235034	15177	92067	723686	1194
1,279,616	7388	13421	125642	244736	14367	92418	780875	769
1,336,564	5934	13155	130577	255761	16288	92548	819298	3003
1,398,377	6094	13779	134654	262950	15009	91538	871420	2933
1,595,719	8710	16033	147961	333614	14937	94811	978845	808
1,688,341	8562	16454	149444	346534	15936	96106	1054433	872
1,763,267	8947	17727	154890	367165	16241	98482	1098747	1068

Table 4: Sample data of roads from 2005 to 2020

A roads									
National	**Western**	**Central**	**Southern**	**Northern**	**Eastern**	**North western**	**North central**	**Uva**	**Sabaragamuwa**
4339	372	471	353	734	620	408	495	471	415
4339	372	471	353	734	620	408	495	471	415
4339	372	471	353	734	620	408	495	471	415
4314	374	471	325	734	620	408	495	471	416
4220	374	409	347	734	620	354	495	471	416
4220	374	409	347	734	620	354	495	471	416
4220	374	409	347	734	620	354	495	471	416
4216	374	409	347	734	620	353	494	469	416
4219	374	409	347	734	620	353	495	471	416
4219	374	409	347	734	620	353	495	471	416
4219	374	409	347	734	620	353	495	471	416
4219	374	409	347	734	620	353	495	471	416
4215	374	409	347	734	620	352	492	471	416
4215	374	409	347	734	620	352	492	471	416
4215	374	409	347	734	620	352	492	471	416
4215	374	409	347	734	620	352	492	471	416

Table 5: Sample data of GDP from 2005 to 2020

GDP									
GDP National	GDP Western	GDP Central	GDP Southern	GDP Northern	GDP Eastern	GDP North western	GDP North central	GDP Uva	GDP Sabaragamuwa
1403287	675239	133143	133672	37400	68632	144444	55852	59465	95440
1562739	776846	133880	155035	43126	95880	143167	57950	63817	93038
1800750	925075	165509	160200	52987	87369	152925	65527	76687	114471
2098003	1065154	177539	187456	63063	99239	186486	90726	95062	133278
2484191	1243653	217843	230491	72722	117192	231974	102378	114843	153095
3578688	1663758	343804	377469	104224	185474	353670	142608	176997	230684
4410681	2003056	430579	464722	139001	246436	438606	206748	200102	281431
4835290	2216346	473416	509052	155827	279363	466041	221293	219293	294659
5604102	2512908	562744	598975	189739	333968	534831	266954	253178	350805
6543310	2894427	644332	718768	242512	379184	655182	305975	297334	405596
7578554	3243854	775581	834286	277828	478401	760148	379243	361975	467238
8939253	3773701	935650	901996	302265	507318	974762	456296	465533	621732
9657195	4003402	1014848	963229	379416	529613	1036890	523128	524450	682219
10154841	4048326	1076672	1025424	419791	579052	1078859	597866	564938	763913
10910258	4340612	1147127	1094403	455100	625815	1165844	630473	629877	821007
11723298	4654001	1222192	1168022	493379	676354	1259842	664858	702281	882368

3.2. Data Analysis

In the selected study area of Sri Lanka, a model was developed to estimate the marginal productivity of vehicles and roads using the organized data. The independent variable, GDP, and the dependent variables, Vehicle stock (VSK) and Road stock (RSK), were identified. The Cobb Douglas function was employed to establish a productivity relationship between GDP, VSK, and RSK. Regression analysis was then conducted to examine the relationship between these variables and determine their significance. This analysis yielded the "unit changes in GDP when unit changes in VSK and RSK" as a measure of productivity. Additionally, log-linear regression was applied to assess the relationship between the variables in terms of percentage changes, providing insights into the "percentage changes in GDP when percentage changes in VSK and RSK" as an indicator. To account for the provincial variation, the data was stacked and categorized with the inclusion of dummy variables, enabling the examination of relationships at both the provincial and national levels.

Equations:

Cobb-Doulas Production Function (Equation 01)

$$GDP(i) = \beta_0 * {X_1}^{\beta_1} * {X_2}^{\beta_2}$$

Linear Production Function (Equation 02)

$$Log\big(GDP(i,j)\big) = Log(\beta_0) + \beta_{1,i} * LogX_{1,i} + \beta_{2,i} * LogX_{2,i}$$

If $Log(\beta_0) = \alpha$,

$$Log\big(GDP(i,j)\big) = \alpha + \beta_{1,i} * LogX_{1,i}\beta_{2,i}\ LogX_{2,i}$$

With Dummy variables

$$Log\big(GDP(i,j)\big) = \alpha + \beta_{1,i} * LogX_{1,i} + \beta_{2,i} * LogX_{2,i} + \textstyle\sum_{i=0}^{9}(Di\ d_i)$$

Log Linear Function (Equation – 03)

$$Log\left(Log\big(GDP(i,j)\big)\right) = \gamma + \beta_3 * Log\big(LogX_{1,i}\big) + \beta_4 * log\big(LogX_{2,i}\big)$$

With dummy variables

$$Log\left(Log\big(GDP(i,j)\big)\right) = \gamma + \beta_3 * Log\big(LogX_{1,i}\big) + \beta_4 * log\big(LogX_{2,i}\big) + \sum_{i=0}^{9}(Di * d_i)$$

After applying this method, the data set was transformed into a cluster data set, which represents the primary clustering schedule of road transportation in Sri Lanka. Two methods were employed using the cluster data set. First, the values were estimated considering the total Vehicle stock (VSK) and Road stock (RSK). Then, the roads were expanded to include categories such as A, B, and E, while the vehicles were categorized as omnibuses, private coaches, dual-purpose vehicles, private cars, land vehicles, goods transport vehicles, motorcycles and three-wheelers, and others. Regression analysis was utilized for this estimation. Additionally, three main econometric models were mentioned, which were applied to estimate productivity:

- Linear (or log-linear) regression using panel data.
- Linear (or log-linear) regression using stacking data.
- Linear (or log-linear) regression using cluster data.

The estimation of marginal productivity of roads' values in this study was based on the utilization of regression analysis as a statistical method, incorporating theoretical principles.

MRP of Roads
$$MRP_{RSK} = \frac{\Delta GDP_i}{\Delta RSK_i}$$

MRP of Vehicles
$$MRP_{VSK} = \frac{\Delta GDP_i}{\Delta VSK_i}$$

Elasticity of MRP of roads
$$\%MRP_{RSK} = \frac{\%\Delta GDP_i}{\%\Delta RSK_i}$$

Elasticity of MRP of vehicle
$$\%MRP_{VSK} = \frac{\%\Delta GDP_i}{\%\Delta VSK_i}$$

4. Data Analysis and Results

This research employed three types of analysis to examine the significance of values across different models and assess the significance of the estimation method.

Table 6: Data Analysis Approach

Data Analysis approach		
Stacking data Analysis	All vehicles	Type I
	All Roads	
Cluster data I Analysis	All vehicles	Type II
	All roads	

Cluster data II Analysis	Expanded vehicle type into 8 categories	Type II
	Expanded road types into 3 categories	

4.1. Stacking Data Analysis

The primary goal of analyzing expressway user behaviour is to address a specific research objective: determining the long-term reactions of expressway users to an increase in toll prices. This analysis relies on data obtained from a survey conducted among expressway users, serving as the main source of information for this study. To conduct this analysis effectively, all the data collected must be consolidated into a single comprehensive view. Once the data set is prepared, regression analysis can be performed to derive insights and draw conclusions.

4.1.1. Estimation of vehicle and road productivity analysis.

Table 7: Stacking data analysis

No	Model		R Square	Intercept	VSK	RSK
1	Model 1	National	0.93	-418316.90	2.14***	466.25*
2	Model 2	Western	0.97	18653595.92	4.49***	(-)8152.93**
3	Model 3	Central	0.91	-555512.94	4.07***	71.67
4	Model 4	Southern	0.93	-894409.28	1.72***	391.79
5	Model 5	Northern	0.76	-141267.69	0.32	127.22***
6	Model 6	Eastern	0.93	-317302.67	2.07***	158.07**
7	Model 7	North-western	0.89	-131481.97	1.52***	79.88
8	Model 8	North central	0.98	5493.01	2.19***	-35.86
9	Model 9	Uva	0.97	-192771.60	3.05***	53.91**
10	Model 10	Sabaragamuwa	0.96	236198.82	2.92***	-139.29

The above table shows the analysis of estimating the productivity of vehicle and roads where the r square value is more than 0.76 for all the models considered. This shows that the data fit well in the regression model. And for each model the productivity regression equation can be formulated using the values of VSK, RSK, and Intercept as provided in the table.

4.2. Cluster Data Analysis

This analysis serves the research's subsequent objectives, namely the estimation of demand elasticity. The data utilized in this study are primarily sourced from the original data set. The survey form captured responses for two types of fluctuations, with answers provided on a weekly basis. These responses were used to calculate the weekly volume, which was then extrapolated to estimate annual volume. This approach was applied to all the fluctuations related to price and income.

After employing the stacking method and considering provincial-wise marginal productivity, certain values were identified as not statistically significant. Consequently, the total road network was divided into segments A, B, and E.

In Sri Lanka, road transport follows a clustering pattern, with Colombo serving as the primary commercial center. As a result, a significant number of people reside in the western province. Given the commercial activities, many individuals commute from the western province to other provinces. Therefore, the western province plays a central role in this transport cluster.

4.2.1. Estimation of vehicle and road productivity.

To enhance the accuracy of toll price elasticity estimation, Chapter 3 focuses on Category I vehicles. However, within this category, there exist 7 distinct types of vehicles. In order to obtain more precise estimated values, Category I vehicles have been further divided into two subgroups, as illustrated below,

Type I vehicles encompass all vehicles categorized as cars, while Type II vehicles consist of Dual-Purpose Vehicles and Light Motor Lorries. Toll price elasticity has been estimated separately for these two types of vehicles. The estimation process involved analyzing two fluctuations of toll prices: a 20% decrease and increase, as well as a 40% increase and increase.

Table 8: Cluster data analysis

Model		R Square	Intercept	VSK	RSK
Cluster 1	Western to Southern	0.69	-10528645.77	2.73***	7488.18***
Cluster 2	Western to Sabaragamuwa	0.94	-3892589.62	4.72***	2946.70***
Cluster 3	Western to Northwestern	0.93	-9533213.23	2.94***	6853.05***
Cluster 4	Western to Sabaragamuwa to Central	0.77	-741606.54	6.69***	168.51
Cluster 5	Western to Nor west to Nor cent	0.84	-5827071.75	2.42***	4576.08***
Cluster 6	Western to Nor west to Nor cent to East	0.83	-5117799.87	2.35***	4131.51***
Cluster 7	Western to Nor west to Nor cent to North	0.85	-6030044.68	2.41***	4703.34***
Cluster 8	Western to Nor west to Cent to Uva	0.57	-2010965.24	4.06***	1326.99***

5. Conclusion

The expressway network in Sri Lanka plays a significant role in the country's overall roadway system. The demand for this road network has been steadily increasing. Particularly, the Outer Circular Highway section has been instrumental in reducing traffic congestion within Colombo city. However, there is still a phase remaining to be constructed in this section of the expressway.

The travel pattern of expressway users is particularly attractive to those heading to Colombo. The analysis of user behavior indicates a considerable demand from students for this road section. Due to its relatively short distance and comparatively low price, it is affordable for certain categories of students. Additionally, the majority of daily commuters using this network are between the ages of 26 and 35.

Regarding toll price increments, lower-income individuals are more willing to shift their transport mode as a long-term response. On the other hand, high-end users of this road network have two options: continuing to use the road at the same frequency despite price increases or changing their residences, given their financial capability to afford a new residence and use the road as frequently as before.

The toll price elasticity values for Type I vehicles range from (-1.95 to -2.64) for toll price increases and (-0.78 to -0.80) for toll price decreases. Type I vehicle users typically make 5 trips per week, resulting in less demand for trips when toll prices decrease and a significant decrease in travel demand when toll prices increase.

For Type II vehicles, the toll price elasticity values range from (-2.08 to -3.77) for toll price increases and (-0.49 to -0.66) for toll price decreases. Type II vehicle users currently make enough trips per week and do not show much demand for weekend trips. Therefore, their demand for trips decreases when toll prices fall.

Regarding income elasticity, the selected road section shows characteristics of a normal good. When income increases, there is not much demand for trips on this road. However, when income decreases, there is less demand for the expressway.

For the increase in income, the elasticity of Category I vehicles varies from (0.55 to 0.59), and for Category II vehicles, it varies from (0.43 to 0.54). This indicates that Category I demands more trips than Category II among high-income individuals because Category I users currently make fewer trips per week than Category II users.

When income falls, Category I individuals reduce more trips than Category II individuals, as Category I individuals have comparatively lower incomes than Category II. The income elasticity change when income falls, for Category I, varies from (1.53 to 1.74), and for Category II, it varies from (0.79 to 1.06).

6. Recommendation and Future Research

Sri Lanka's expressway roads are specifically designed for certain types of vehicles and do not accommodate bicycles, motorcycles, three-wheelers, or other land vehicles. As a result, there is an unmet demand for this road infrastructure in the country. Despite the existence of expressways, regular highways in Sri Lanka continue to face congestion because most vehicles still utilize these conventional routes.

The category of vehicles unable to use the expressway includes those commonly used by middle-level individuals, such as bicycles, motorcycles, three-wheelers, and land vehicles. This indicates that this particular social class has been excluded from accessing the benefits of expressway roads. It suggests that the current pricing and other methods employed for the expressway may not be affordable for certain segments of the population. Additionally, even though there are public transport services available on the expressway, the pricing system does not align properly.

Private vehicle owners may end up paying less for a similar distance on the expressway compared to passengers using public transport buses. Consequently, some members of society, particularly those who do not own vehicles, are excluded from benefiting from the expressway network.

To address these issues and make the expressway accessible to all social classes in the country, a proper pricing system should be implemented. This way, everyone can afford and benefit from the convenience and efficiency of the expressway network.

This study focused solely on examining price and income elasticity, disregarding various other factors that could have a significant impact on travel demand. These unexplored factors remain outside the scope of this research. In contrast to other countries, which employ various estimation methods, this research solely relied on user survey data to estimate elasticity. The incorporation of time series data analysis and regression analysis could have resulted in a more robust and effective model for addressing this problem.

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