FUEL TAX VS. ROAD PRICING WITH CHARGE COLLECTION

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KEYWORDS

Congestion costs, pollutant emissions, congestion charging, fuel tax and simulation

ABSTRACT

A method based on a computer simulation is described here, how to determine emissions in congested traffic flows and evaluate them in monetary units and thus set correct congestion unit charges for different vehicle types. Also comparison with the fuel tax accumulation is done. In the congested traffic flow the average speed is decreased and the fuel consumption as well as pollutant emissions are increased. In the simulation study different type vehicles are driven in various traffic conditions, where the congestion degree varies including also free traffic conditions. The results show very clearly, how efficient and economic the fuel tax is to response to the socio-economic congestion costs as well as the infrastructure costs. No expensive electric charge collection systems are needed.

INTRODUCTION

In numerous large cities and other densely populated areas traffic congestion causes a lot of problems. Except time loss emissions are increased, because traffic flows are not steady. In congested conditions vehicle engines operate mainly in transient states, where decelerations and accelerations follow each other. In the acceleration phases fuel is burnt followed by huge amounts of pollutant emissions. The emissions are relative to the used fuel, and in addition between the carbon dioxide and the fuel consumption there is a linear dependence in practice.

The time loss is caused to the road user him/herself, while the emission damages are caused to all partners. Therefore today in some places congestion charge systems have been implemented.

Although in reality emissions do not cost anything, in many countries governments have set shadow unit prices for different items of the pollutant emissions in order to evaluate impacts of emissions. On the other hand in Western European countries (European Union) an essential part of the fuel price is tax, and as shown in several earlier ITS presentations (e.g. ITS 2003 in Madrid, Spain and ITS 2007 in Beijing, China) the increased accumulated fuel tax in congested conditions covers excellently congestion “costs” based on the shadow unit prices set by the government. The fuel tax is a very economic and efficient way to collect “congestion charges”, and any other systems are not needed. It is just necessary that the fuel tax level is appropriate, and in these EU countries it is.

However, there are several countries, where the fuel tax is negligible or the fuel tax does not exist at all. If congestion will be charged, in these countries it must be done in another way. The correct pricing should be based on the cost responsibility, and then in addition to the predefined shadow unit prices for the different pollutants the real amounts of them should be censored and recognized by those charging systems. However, there are no systems, neither manual nor automatic (electric), which could do this.

The solution for this problem is a vehicle motion simulation system, which is based on engine maps, vehicle dynamics and other technical data of vehicles and roads. Traffic congestion can be described by terms of the target speed and the average speed, and these quantities can also been censored and recognized by the electric congestion charging systems. By simulations the impacts of the congestion degree (= average speed relative to target speed) on emission amounts (as well as on the fuel consumption) can be determined, and multiplying these by the shadow unit prices correct congestion costs can be evaluated for different vehicle categories as functions of the congestion degree.

This presentation shows some examples on the Ring road III in Helsinki area. The congestion degree in the examples varies from 0 to 87 percent.

CASES TO BE STUDIED

In this survey the traffic flow is composed of totally six vehicle categories, which are represented by type vehicles as follows:

Vehicle category	Abbreviation	Vehicle mass kg	Rated engine power kW
Passenger car	P	1400	66
Van (light goods vehicle)	V	2300	76
Coach	C	16000	250
Single truck	T	22000	250
Truck + semitrailer (articulated vehicle)	TS	35000	309
Truck + trailer (road train)	TT	50000	345

The analysis concerns the Ring road III around the city of Helsinki in Finland (length 45.6 km). The target speed on this road is 100 km/h for passenger cars, vans and coaches. For trucks of all kind the target speed is 80 km/h and the congestion degree varies from 0 to approximately 87 percent.

The current monetary unit values are the following:

	Gasoline €/l	Diesel fuel €/l
Fuel tax excluding VAT	0.627	0.364
VAT (22 %)	0.138	0.080
Fuel tax including VAT	0.765	0.444

Shadow unit prices for emission items:

	Built up areas €/t	Rural areas €/t
Nitrogen oxides (NO_x)	1170	458
Carbon monoxide (CO)	78.61	53.84
Hydro carbons (HC)	70.20	70.20
Particulate matters (PM)	213000	6640
Carbon dioxide (CO_2)	33.80	33.80

RESULTS

In this context the congestion degree is defined as follows:

$$p = 100\,(1 - v_a/v_t)$$

where: p = congestion degree [%]
v_a = average speed (=proceeded distance/used time) [km/h]
v_t = target speed [km/h]

So if the average speed is equal to the target speed, the congestion degree is 0, and the congestion degree is 100, when nothing moves.

In the general form the cost model is as follows:

$y = C_0 + C_1\,p + C_2\,p^2$ for light vehicles (passenger cars and vans) and
$y = C_0 + C_1\,p^{C_2}$ for heavy vehicles (buses/coaches and trucks)

where: y = costs [€/km]
p = congestion degree [%]
C_0, C_1 and C_2 = model coefficients

If y represents emission costs, the congestion costs can be defined as the increase of emission costs compared to the driving state with the congestion degree of zero (0). So

$z = C_1\,p + C_2\,p^2$ for light vehicles
or respectively
$z = C_1\,p^{C_2}$ for heavy vehicles

where: z = congestion costs [€/km]
p = congestion degree [%]
other symbols as above

In this case v_t = 100 km/h for light vehicles and 80 km/h for heavy vehicles, and the model coefficients by the type vehicles of those vehicle categories are:

VEH. CAT	FUEL TAX		EMISSIONS COSTS built up areas		EMISSION COSTS rural areas	
	C1	C2	C1	C2	C1	C2
P	-.000115754	.000006809	-.000041682	.000001194	-.000040050	.000001152
V	-.000140871	.000006682	-.000007351	.000000735	-.000009183	.000000675
C	.000057262	1.6675	.000025110	1.5816	.000016543	1.6262
T	.000161741	1.5386	.000024467	1.6791	.000028563	1.6017
TS	.000243751	1.5104	.000044066	1.6046	.000046565	1.5531
TT	.000888445	1.2527	.000000673	2.7761	.000116849	1.3820

The results can also be seen in the figures according to the next list.

Fig. 1 Passenger car: Fuel tax and congestion costs vs. congestion degree
Fig. 2 Van (light goods vehicle): Fuel tax and congestion costs vs. congestion degree
Fig. 3 Coach: Fuel tax and congestion costs vs. congestion degree

Fig. 4 Single unit truck: Fuel tax and congestion costs vs. congestion degree
Fig. 5 Truck + semi-trailer: Fuel tax and congestion costs vs. congestion degree
Fig. 6 Truck + trailer: Fuel tax and congestion costs vs. congestion degree
Fig. 7 All type vehicles: Fuel tax and congestion costs vs. congestion degree

CONCLUSIONS

The simulation of vehicle motion is a very efficient way to determine the correct unit values of congestion charges for different vehicle types and their dependencies on the congestion degree. However, in this case the costs caused by the system itself (investment, operation and administration) must be included in these unit prices, too.

The fuel tax, where it is applied, is more efficient and economic way to collect congestion charges. Between congestion costs and fuel tax accumulation there is a very good relationship as the results show.

The results show also a very interesting feature concerning light vehicles (passenger cars and vans). In general both the fuel tax accumulation and emission "costs" are increased as soon as the congestion degree is increased from zero (0). In other words the optimum (minimum) is achieved, when the congestion degree is zero (0) or the average speed is equal to the target speed. This is true for heavy vehicles and also for light vehicles, if their target speed were for example 80 km/h rather than 100 km/h in this case.

The model forms for the passenger car and van are polynomials of second degree (parabolas), and their minimum values appear within the range of the congestion degree. So the optimums would be reached at the following congestion degrees and average speeds.

	Fuel tax accumulation		Emission costs built up areas		Emission costs rural areas	
	congestion degree %	average speed km/h	congestion degree %	average speed km/h	congestion degree %	average speed km/h
Passenger car	8.5	91.5	17.5	82.5	17.4	82.6
Van	10.5	89.5	5.0	95.0	6.8	93.2

The explanation is clear. In congested traffic more or less physical work is done against the acceleration resistance, which causes more or less fuel consumption and emissions. However, this work is compensated quite efficiently by the reduced work against the driving resistances (air and rolling), which are decreased with the speed reduction.

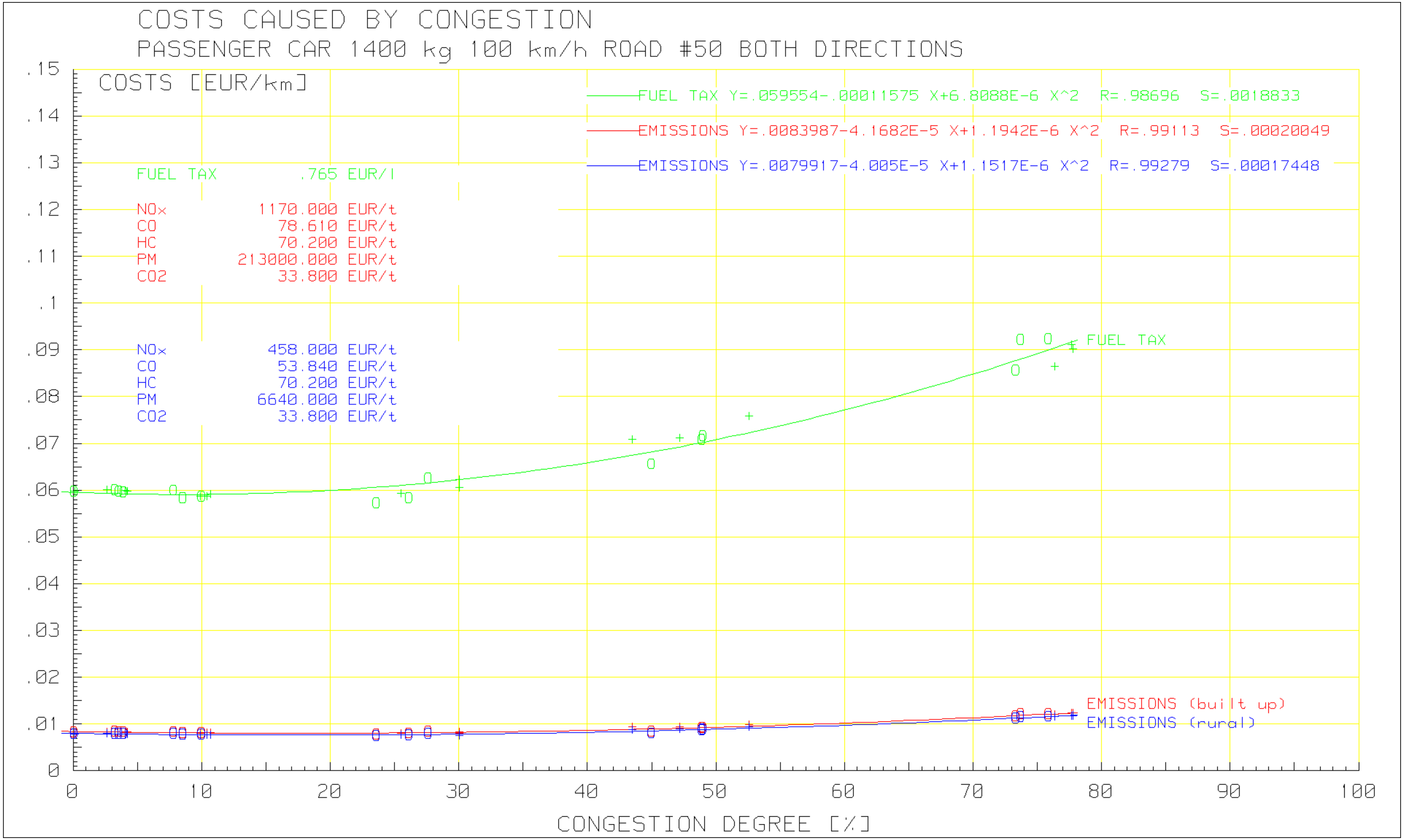

Fig. 1 Passenger car: Fuel tax and congestion costs vs. congestion degree

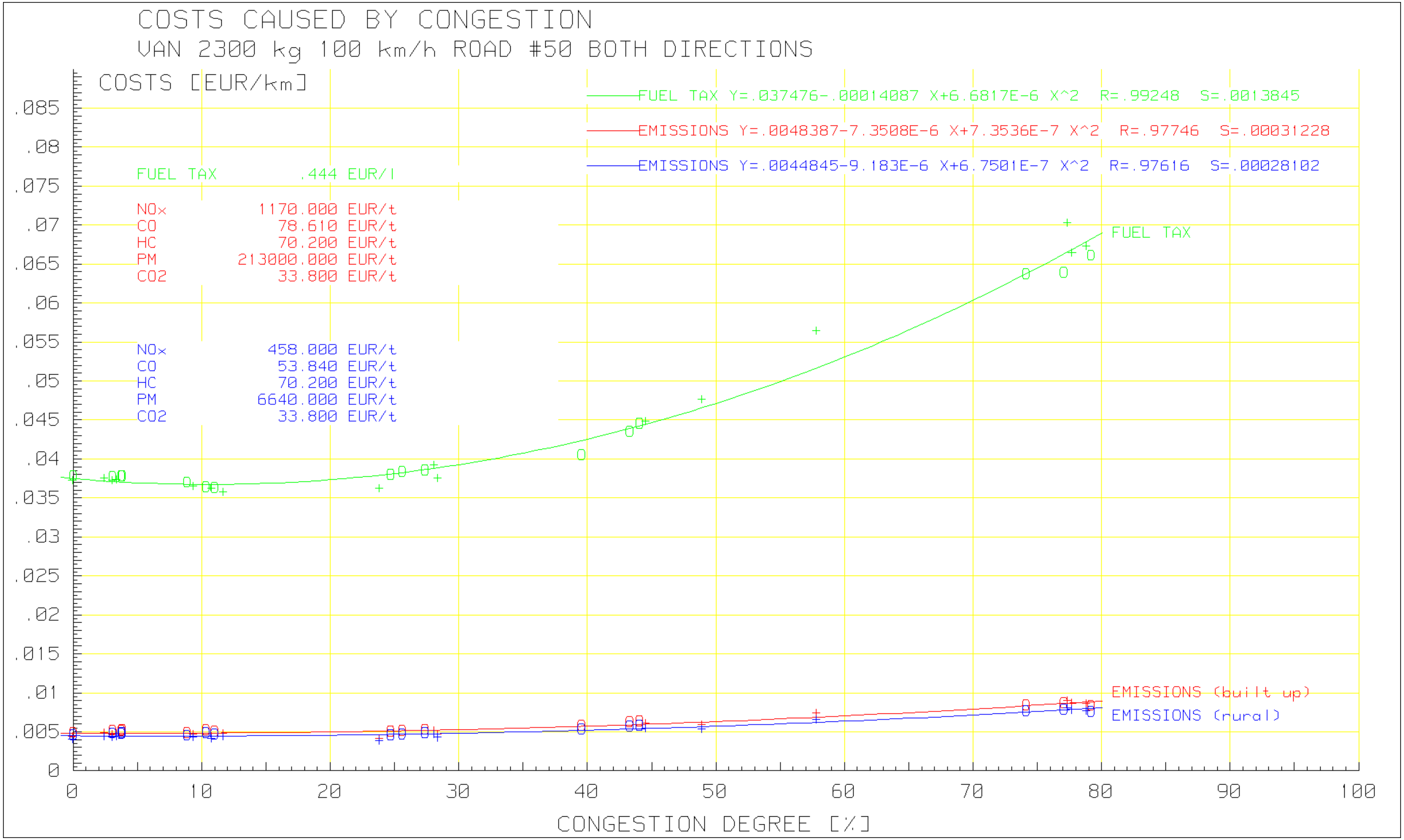

Fig. 2 Van (light goods vehicle): Fuel tax and congestion costs vs. congestion degree

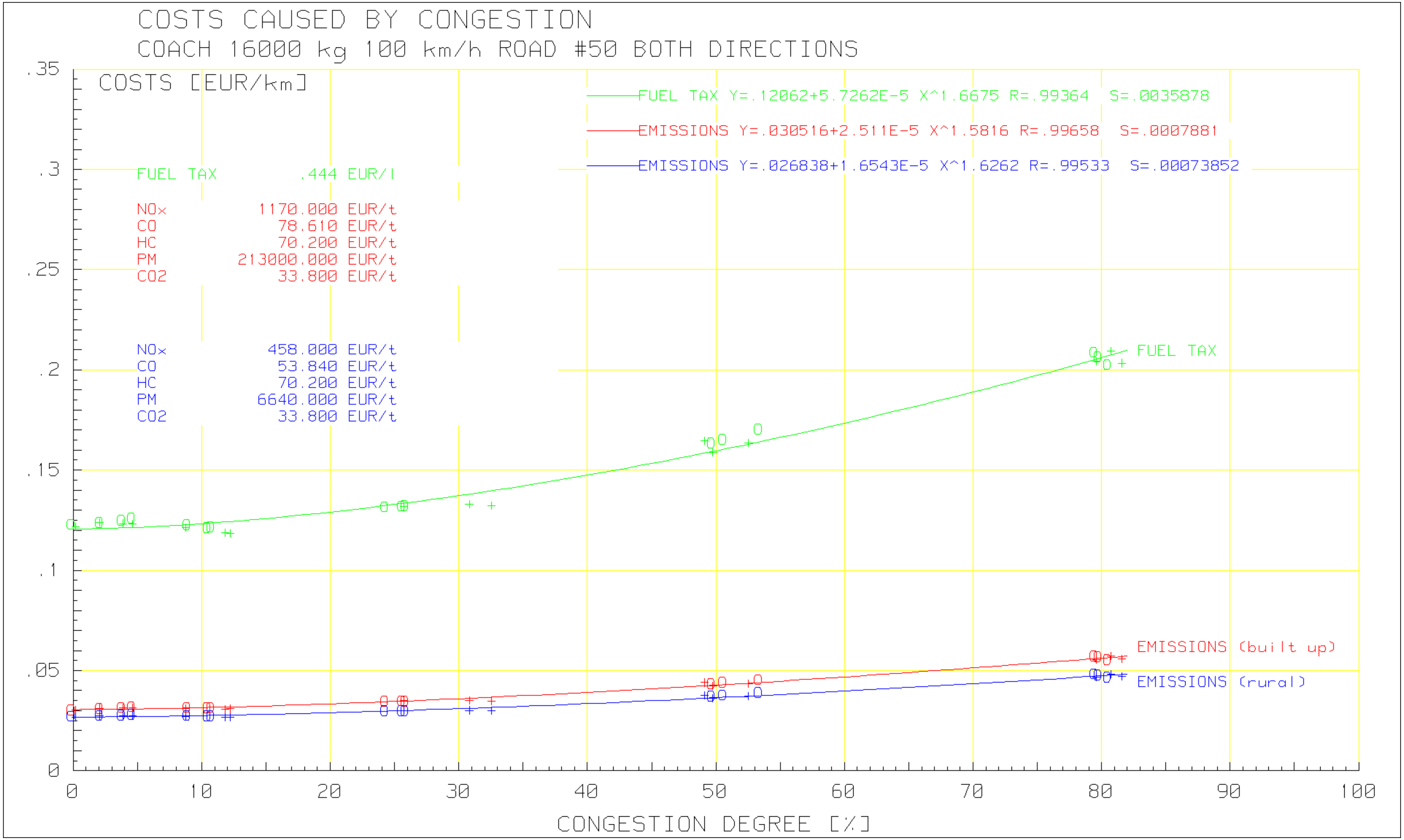

Fig. 3 Coach: Fuel tax and congestion costs vs. congestion degree

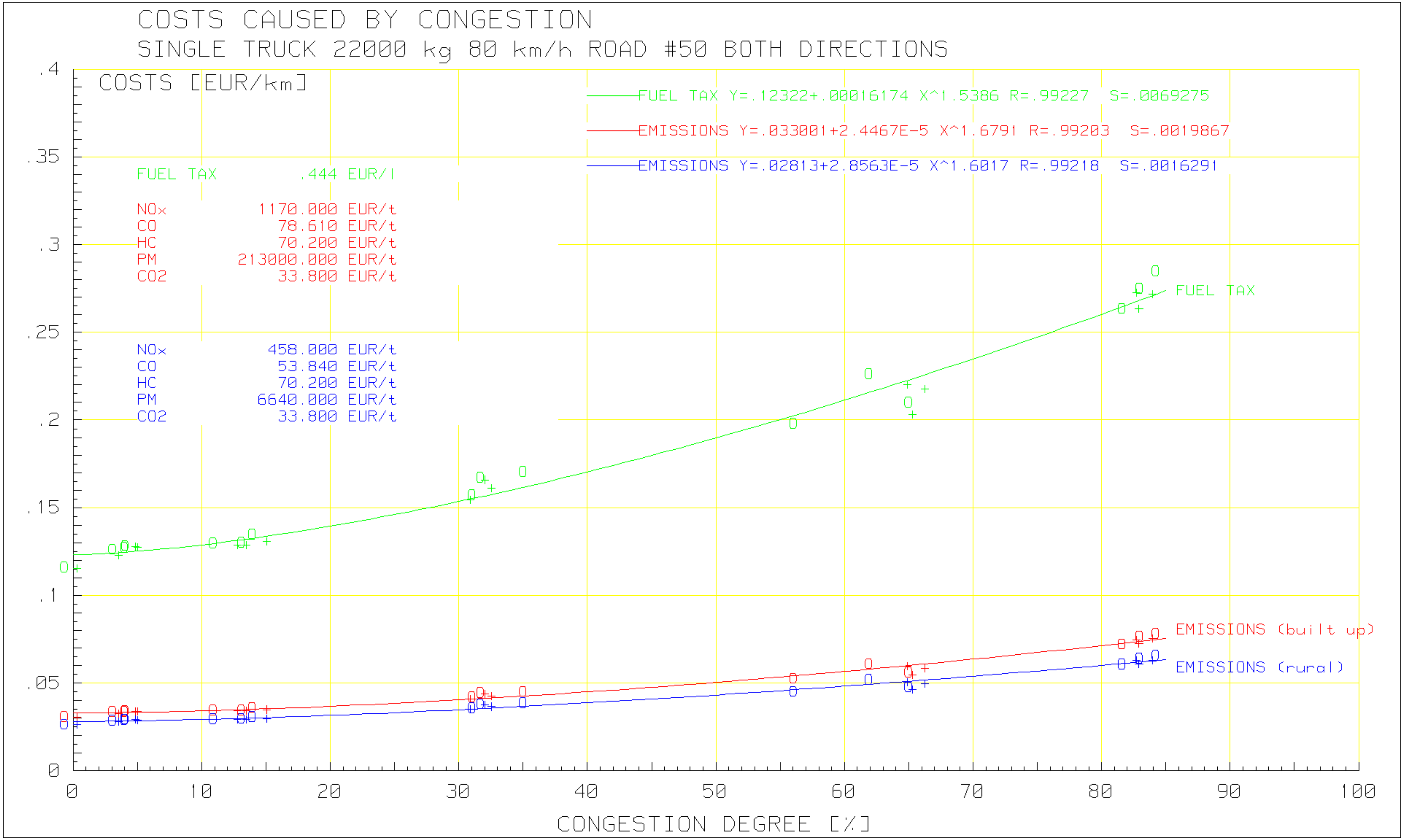

Fig. 4 Single unit truck: Fuel tax and congestion costs vs. congestion degree

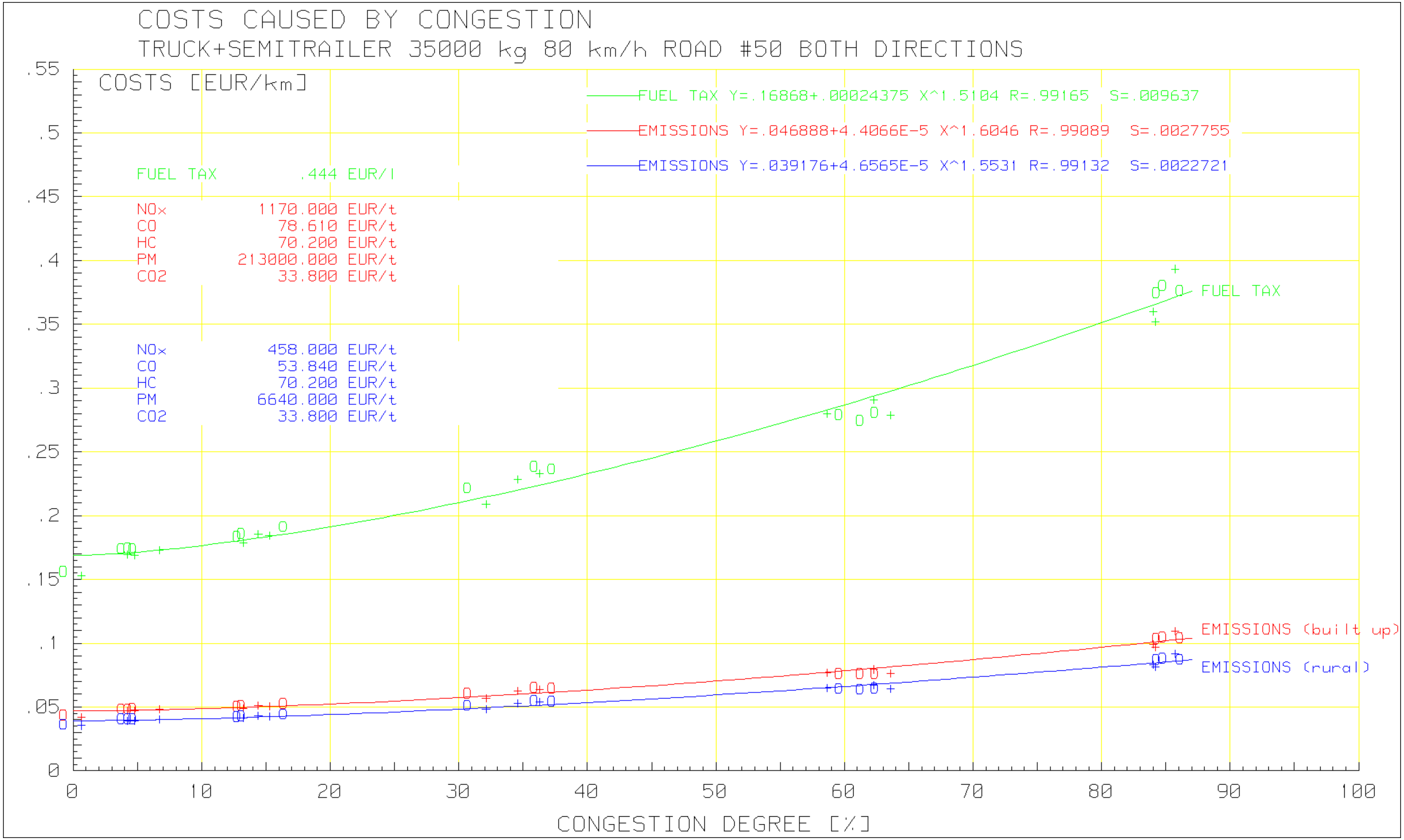

Fig. 5 Truck + semi-trailer: Fuel tax and congestion costs vs. congestion degree

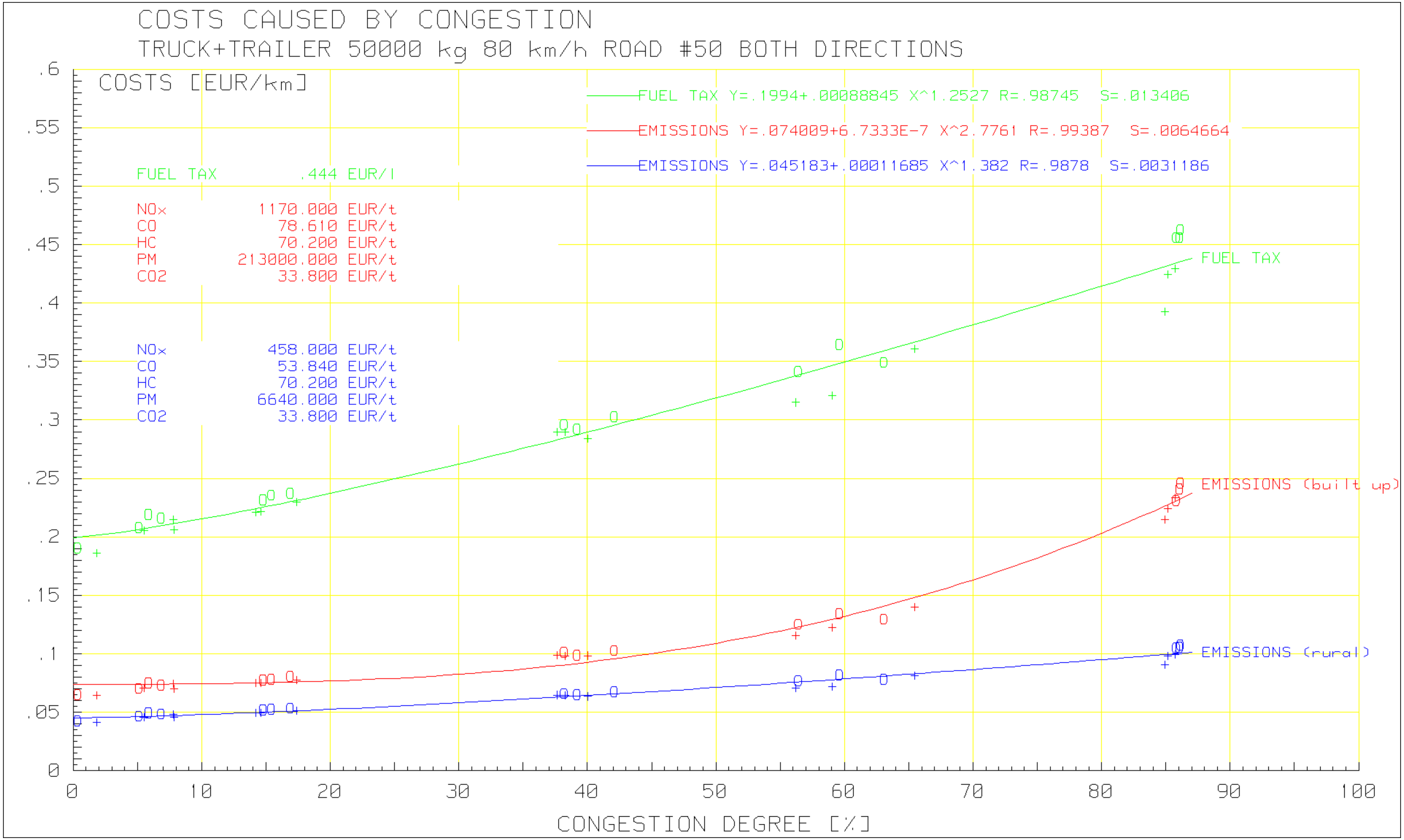

Fig. 6 Truck + trailer: Fuel tax and congestion costs vs. congestion degree

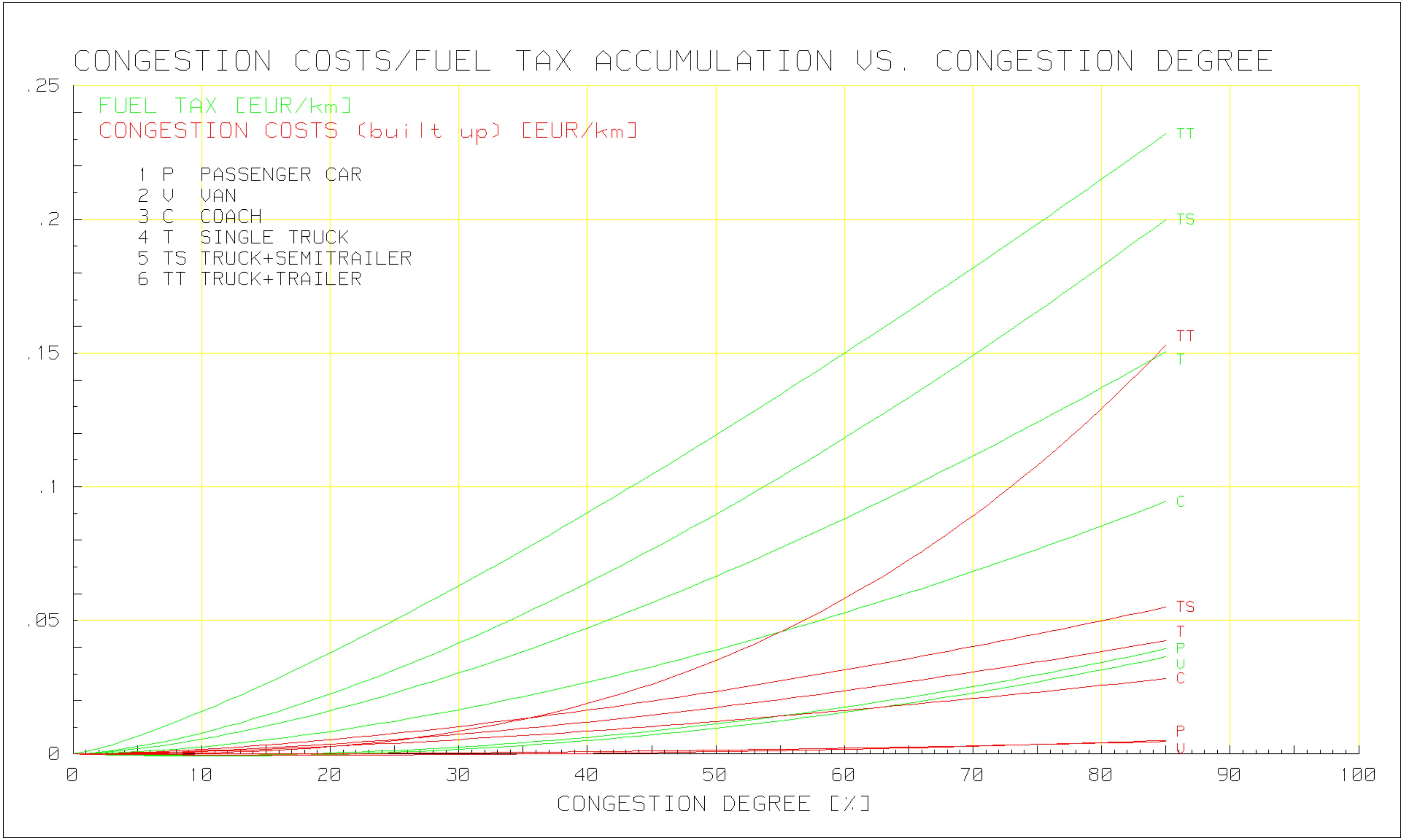

Fig. 7. All type vehicles: Fuel tax and congestion costs vs. congestion degree