🏆 *reviewed paper*

Quantifying the Benefits of Sustainable Transport for the Urban Economy

Wolfgang Rauh

(Dipl.-Ing. Dr. Wolfgang Rauh, Kolschitzkyg. 10/12, 1040 Wien, wolfgang.rauh@chello.at)

1 ABSTRACT

There is ample research on health benefits and benefits due to the prevention of environmental damage induced by the use of sustainable means of transport. For the political acceptance of measures for the promotion of sustainable urban transport it is important in addition to evaluate how a more sustainable system of urban transport directly affects urban businesses with regard to transport cost and productivity. This question leads to the very purpose of urban transport which is providing accessibility. It can be shown that beginning from a very low percentage any increase in the modal share of car traffic in a given system of urban transport causes accessibility to fall due to increased congestion. With regard to urban businesses this means that access of potential labour force to places of work, the so called „effective size of the labour market" is reduced. Research also has shown that productivity is positively linked to the size of the labour market. Hence it is possible to attribute a marginal cost or benefit to any increase or reduction of urban car traffic. In case of the city of Vienna this benefit can be estimated at 4000 to 5000 Euro per year for every commuter changing from car to public transport walking or cycling. This adds to the already well researched benefits brought about by the reduction of congestion cost.

Keywords: Benefits of agglomeration, Sustainable Transport, Urban Businesses, Economic Benefits, Accessibility

2 BENEFITS OF AGGLOMERATION

2.1 Productivity depends on the effective size of the labour market

It has been shown that the productivity of businesses in urban areas depends on the so called „effective size of the labour market" with the latter depending mainly on average speed of commuters and urban density. In an article „Size, Sprawl, Speed and the Efficiency of Cities" [Prud'homme R., Lee C., 1999] it is stated as follows: „The hypothesis put forward here – and tested – is that the efficiency of the transport system (in short: speed) and the relative location of jobs and homes (in short: sprawl), which are the output of transport policies and urban policies resspectively, combine with city size to determine the effective size of the labor market. This effective size of the labor market – the number of jobs that can, on average, be reached in less than t minutes – in turn is a major explanation of labor productivity."

Prud'homme and Lee look at efficiency which is "defined as labor productivity, that is output per worker." What is relevant for the following discussion is the elasticity of this economic output (Y) with regard to changes in the effective size of the labour market (L). By analyzing data from 22 French Cities Prudhomme and Lee come to the conclusion that an "elasticity of 0.18 seems a reasonable order of magnitude." The analysis was done for labour market sizes within 20, 25 and 30 minutes isochrones (L(t) = L20, L25 and L30). An analysis of data from three South Korean cities (Seoul, Busan, Daegu) shows similar results.[1]

Based on these findings, the gross regional product of a city per head of population (labelled GRP) where the effective size of the labour market L is a function of the modal share of car travel m_c and with "ceteris paribus" assumptions can be written in logarithmic version as follows [derived from Prud'homme & Lee, 2001, p. 140]:

(1) $$\ln GRP = C + \mathcal{E} * \ln L(m_c)$$

C is constant and $\mathcal{E}$ is the elasticity of productivity with regard to the effective size of the labour market.

2.2 Elasticity of producitvity with regard to labour market size

There has been research done into many factors affecting agglomeration benefits like city size, employment density or size of certain industries. A comprehensive overview is given among others by Graham [Graham, 2005]. One important aspect is mentioned by Prud'homme and Lee already in their introduction. As there is no consistent data available for total productivity in cities they had to settle for output per worker. Attractive

[1] The elasticity in question is 0.24 in average for the three cities.

cities attract investment which amplifies agglomeration effects caused by the size of the labour market. This component of agglomeration is merely a relocation not a creation of additional wealth. Taking into account all these aspects, it seems to be appropriate for a cautious approach to use 0.06 or 6% instead of 0.18 as estimate for agglomeration benefits related to the effective size of the labour market [Rauh W., 2008, p.71].

3 HOW URBAN TRANSPORT AFFECTS THE SIZE OF THE LABOUR MARKET

3.1 Defining an indicator for the effective size of the labour market

The aim is now to analyze how changes in modal split affect the average speed of travel and hence the effective size of the labour market at a given urban density and with a given urban transport infrastructure. For this purpose a simple modelling approach which shows the basic mechanisms and allows a rough estimate of producitvity effects is applied to the example of Vienna. For this simplified approach it is assumed that jobs as well as homes are evenly spread over the area of the city and that this area is larger than the labour market which can be reached within 30 minutes travel time. An indicator for labour market size (L) can be described as a function of the average speed of trips by car (V_c) and the average speed of trips by public transport plus cycling plus walking (V_p). Public transport, walking and cycling are summarized under "other transport".[2] What is further required is the share of car trips M_c respectively the share of other transport M_p with $M_c + M_p$ being 100%. The indicator $L(M_c)$ is a proxy for determining relative changes in the effective size of the labour market caused by changes in the modal share of car trips M_c. It is calculated as follows:

$$L(M_c) = V_c^2 * M_c + V_p^2 * (1-M_c) \quad (2)$$

V will be given in kilometres per hour (km/h) and M – the modal share with regard to workday trips – in percent with $M_p + M_c = 100\%$. If it were multiplied by the average density of available labour force and the speeds were changed from cartesian to polar velocity and the result multiplied by π it would be an estimate of the number of potential employees within a one-hour isochrone.[3]

The model for calculating the speed of travel is based on the modal split of transport performance (person-kilometres). For the effective size of the labour market, as shown in equation (2) the modal split of trips is relevant. As the size of the labour market is defined by the same time-span for all travel modes the modal share of car trips M_c can be derived from the modal share of person-km travelled by car m_c by taking the average speed of travel into account:

$$M_c = (m_c/V_c)/(m_c/V_c + (1-m_c)/V_p) \quad (3)$$

3.2 Impact of the modal share of car travel on speed and labour market size

V_c as well as V_p depend on traffic load. At a given intensity of person-traffic, traffic load varies with modal split as car traffic causes more PCU-km per Passenger-km than more efficient types of transport. With rising share of car travel the regulation of surface traffic has to be adapted to accomodate higher traffic loads. This affects all types of transport and adds to the delays caused directly by congestion. The model for calculating the impact of modal split on the speed of door-to-door traffic (as shown in Fig.1) is based – among other – on empirical data on the average speed of travel measured in Vienna during workdays at varying traffic load (Rauh, 2008 p.41).[4]

[2] This simplification is not far fetched. Walking, cycling and public transport are complementary and therefore inseparable in practice. Together they form a typical and very common way of getting around in a city like Vienna. For short trips walking or cycling are fastest among „other transport“. For longer trips public transport is the most attractive option combined with walking and / or cycling to and from stations.

[3] Absolute figures are not required as only relative changes are relevant in the context of this paper.

[4] With q being actual traffic load relative to traffic load at peak time the average time to travel 1 kilometre by car in Vienna can be estimated at $1{,}91 - 0{,}16\,q + 1{,}31\,q^2$ [min/km] (see Rauh, 2010, p. 22). With additional data from mobility surveys an estimate for travel time respectively speed from door to door for car travel and other transport can be given.

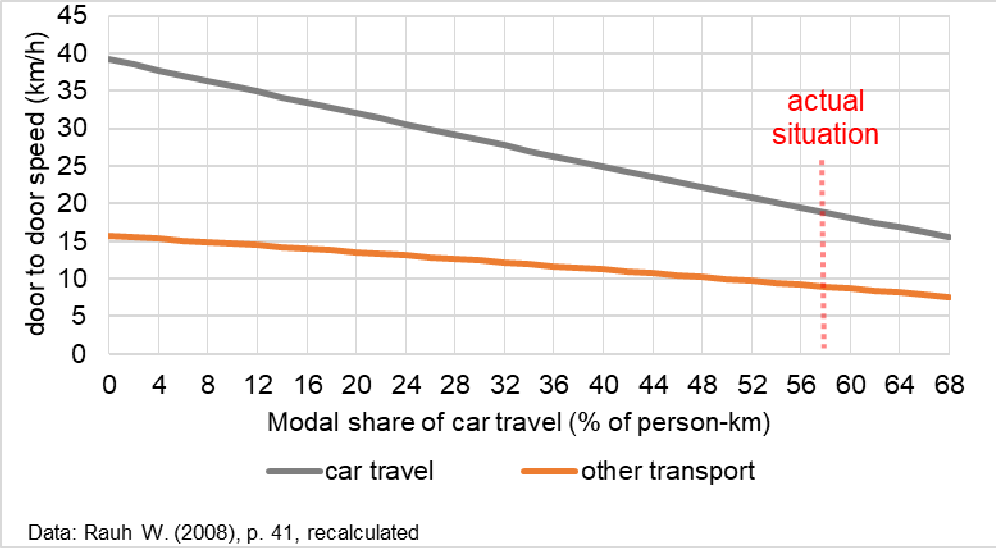

Fig.1: Impact of the modal share of car travel on average speeds of travel V_c and V_p

Based on the respective speeds of travel the indicator $L(m_c)$ is determined according to equations (2) and (3).

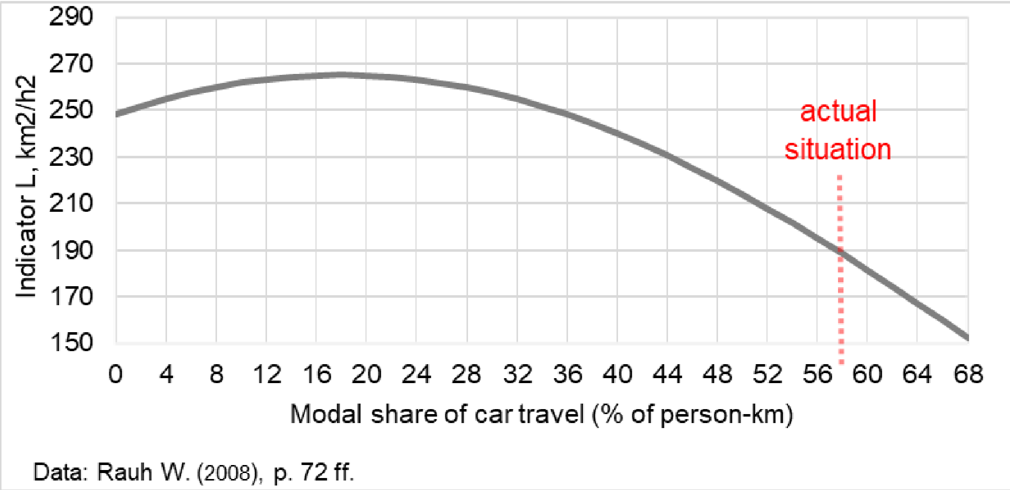

Fig.2: Impact of the modal share of car travel on the effective size of the labour market

Up to 18% of person-kilometres driven by car, increasing modal share of car traffic leads to an increase in the effecive size of the labour market. This is due to the increase in the speed of travel by switching to car-use. Above that limit the effect of the individual increase in travelling speed is more than offset by the individual contribution to the general decline in speed for all means of transport.

3.3 Marginal effect of car travel on producitivity

The creation of wealth could be related to all trips or to commuting trips only. To avoid overstating the effect per trip, the first option is chosen here. It can be assumed though, that the choice of a means of transport for a cummuting trip probably has a higher effect on productivity than it has per trip in general.

The wealth generated in Vienna is 100.3 bn € per year or 185€ per head of population per workday.[5] The number of car trips per head of population per workday can be estimated at 1.085 with m_c = 58% of distances within the urban area travelled by car.[6] Car trips per head of population and workday as a function of m_c is calculated as

(4) $CPH(m_c) = m_c * 1.085 / 58\%$

The impact of the size of the labour market on GRP in Vienna is calculated according to equation (1) with $\mathcal{E}$ = 6% and C derived from the actual values of L, GRP and m_c:

[5] Statistik Austria, data for 2019
[6] Rauh W. (2008), p.125

ISBN 978-3-9504945-0-1. Editors: M. SCHRENK, V. V: POPOVICH, P. ZEILE, P. ELISEI, C.BEYER, J. RYSER, G. STÖGLEHNER

(5) $GRP(m_c) = \exp(C+0{,}06 * \ln L(m_c))$ with $C = \ln 185 – 6\% * \ln L(58\%) = 4{,}9062$

By means of numerical differentiation the marginal effect of additional car trips on $GRP(m_c)$ can be determined. This effect in € per car trip is labelled MRP:

(6) $MRP(m_c) = (GRP(m_c+\Delta m_c) - GRP(m_c)) / ((CPH(m_c+\Delta m_c) - CPH(m_c))$

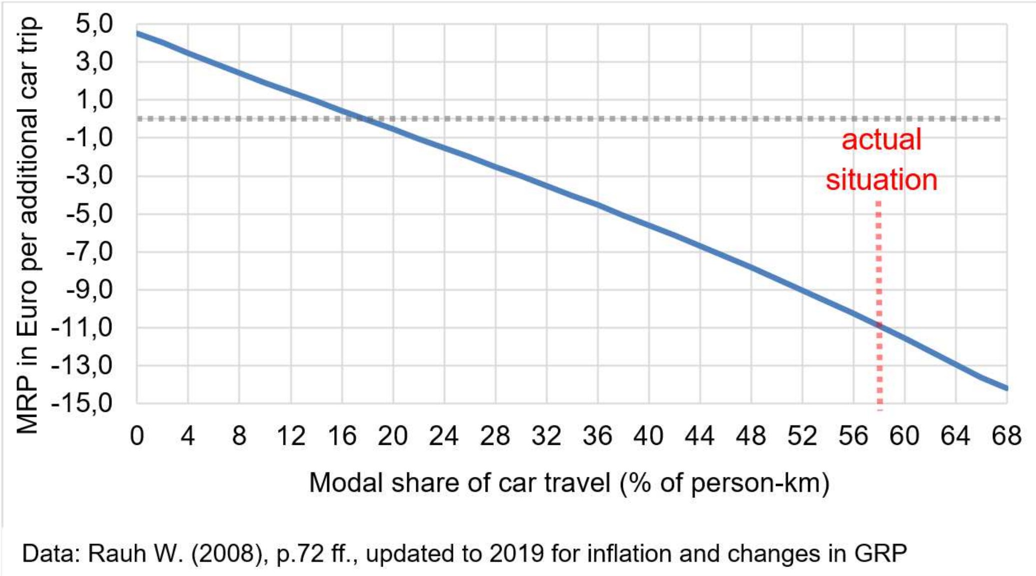

Fig. 3: Marginal effect of peak-time-car travel on economic output in Vienna

If MRP is divided by the average trip length of 4.9 km within the urban area [Rauh W. 2010, p.22] the result is € per car-km respectively so called PCU-kilometres (PCU = person car unit[7]):

It can be recognized that up to a modal share of 18% car travel can be expected to contribute positively to agglomeration effects. Above that level the negative effects of increasing congestion prevail.

4 CONCLUSION

4.1 Short term effects of urban car travel on agglomeration benefits

According to the above result, the marginal effect per additional car-commuter per year on productivity in Vienna can be estimated under minimum-assumptions as a loss of about 5000 Euro in economic output. [8] The annual benefit with regard to productivity which could be gained per year per commuter changing from car to other means of transport would be slightly less than the mentioned amount. Walking, cycling, tram and bus traffic can cause delays and related loss of agglomeration benefits too but it is more than one order of magnitude less than it is for car traffic [Rauh W., 2010, p.24].

Marginal external congestion cost caused by car traffic in Vienna can be estimated at more than 4000 Euro per commuter per year [Rauh W., 2010, p.24].[9] It can be assumed that this amount is partly contained in the beforementioned losses of agglomeration benefits as far as business travel and commercial freight traffic is affected.

4.2 Long term effects of urban car travel on agglomeration benefits:

It could be rewarding to do additional research in the long term effects of car traffic on urban density and on the resulting effects on agglomeration benefits. The point where the contribution of car traffic to productivity turns negative – about 18 percent of transport performance in present-day Vienna – could be moved to higher percentages if density were reduced. This is a tendency that happens “naturally” by the process of suburbanisation. By reducing density the city adapts to a higher traffic load to reach a new optimum of

[7] In traffic enginieering every type of vehicle, depending on its space requirements, is attributed a certain number of PCU

[8] 230 workdays per year, loss of 10.9 Euro caused by reduction of productivity per additional car-trip to or from work at peak time. = 2 * 230 * 10.9 = 5014 Euro per year.

[9] The exact result would be 4481 Euro if the data from 2010 is updated for inflation.

accessibility and hence effective size of the labour market.[10] Even if this new optimum is higher than it was at the original density with above-optimum traffic load, it is still lower than it would have been with reduced traffic load at the original density [Rauh W., 2008, page 42]. Long term adaptation of urban densitiy can slightly reduce the loss of agglomeration benefits by above-optimum car traffic. What is excluded from this consideration apart from environmental cost is also the additional private and taxpayers cost incurred for longer travel distances and the higher cost of infrastructure to serve lower density settlement structures.

5 REFERENCES

GRAHAM D. J.: Transport Investment, Agglomeration and Urban Productivity. Centre for Transport Studies, Imperial College, London, 2005.

PRUD'HOMME R.; LEE, C. W.. Size, Sprawl, Speed and the Efficiency of Cities, in: European Conference of Ministers of Transport (ECMT), Assessing Benefits of Transport, OECD Publications Service, Paris, 2001.

PRUD'HOMME, R., LEE, G.: Sprawl, Speed and the Efficiency of Cities, Urban Studies 36, 1849–1858, London, 1999.

RAUH W.: Einfluss der Verkehrsmittelwahl auf Bevölkerungsdichte und externe Agglomerationseffekte in Großstädten, Dissertation, Technische Universität, Wien, 2008.

RAUH W.: Staukosten – ein starkes Argument für den öffentlichen Verkehr", Der Nahverkehr 7-8/2010 p. 21 – 24, Hamburg, 2010.

6 ANNEX

6.1 List of labels and constant values

Constant/ Label	Description
1,085	actual number of car trips per head of population per workday in Vienna
185	actual size of the gross regional product in € per head of population per workday in Vienna
58%	actual modal share of person kilometres travelled by car in Vienna
6%	actual estimate for the elasticity of GRP with regard to L
CPH	number of car trips per head of population per workday in Vienna
GRP	gross regional product in € per head of population per workday
ε	elasticity of the gross regional product with regard to the effective size of the labour market.
L	indicator for the effective size of the labour market in km^2/h^2
Mc	modal share of car trips (based on number of trips)
mc	modal share of person kilometres travelled by car
MRP	marginal agglomeration effect on gross regional product in € per additional car trip
Vc	average speed of travel from door to door by car in kilometres per hour.
Vp	average speed of travel from door to door by other means of transport in kilometres per hour.

[10] This can be interpreted as a market process whereby residents and businesses gradually move to areas on the fringes of the city where they experience less congestion and higher resulting level of accessibility.

ISBN 978-3-9504945-0-1. Editors: M. SCHRENK, V. V: POPOVICH, P. ZEILE, P. ELISEI, C.BEYER, J. RYSER, G. STÖGLEHNER