Decomposition of the Change in the Amount of Commuting in Denmark 1980-1995[1]

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Introduction

Only very few employed people work in their homes. Most people have to travel in order to reach their place of work – to commute. There are, however, substantial differences between the distances people commute. Some groups of people tend to commute more than others. Female employees commute less than male employees in average for example, similarly do low income workers commute less than high income workers (cf. Budgetdepartementet (1994) and Euro-CASE (1996)). Besides, historically the average commuting distance has changed. In Denmark the average commuting distance has been increasing.

The development in the commuting, defined as the distance the entire Danish workforce has to travel in order to reach their job, from 1980 to 1995 is shown in table 1.

Table 1. Amount of commuting, number of employed people and average commuting distance, 1980 and 1995

	Amount of commuting (1000 km)	Number of employed people (1000 people)	Average commuting distance (km)
1980	33,176	2,551	13.0
1995	41,611	2,639	15.8
Difference	8,434	87	2.8
Per cent	25.4	3.4	21.5

Source: Data from LINE and own calculations.

The data are at municipality level, giving rise to imprecise numbers. According to a survey *Transportvane--undersøgelserne* the average commuting distance was 11 km in 1981 (TU-86 (1988)) and 14.4 km in 1995 (Vejdirektoratet (1996)). This result is based on surveys, i.e. people are asked. It is seen that the growth in average commuting distance due to the above analysis is somewhat smaller than the growth obtained in the surveys (30%)[2].

Commuting in Denmark is the topic in Miljøministeriet (1994). Using data for home and place of work location, the development from 1985 to 1991 is analysed, according to geographical differences etc. Commuting is also analysed in Budgetdepartementet (1994). The issue here is the mobility on the labour market. Commuting is interpreted as an indicator of mobility. The interaction between economic growth and traffic worldwide is discussed in Euro-CASE (1996). It is concluded that there are substantial differences in the relationship between GDP and amount of transport between countries. Furthermore, it is concluded that from 1980 to 1990 the average distance travelled has increased more than GDP for Europe as a whole. Again there are substantial differences between countries. The time spent on travelling is on the other hand more equal in different countries.

With respect to energy consumption and environment, the increased amount of traffic is critical. According to Vejdirektoratet (1996) commuting gave rise to 28% of the kilometres travelled by individuals.

Different factors may have induced the increase in the amount of commuting – for example that individuals have moved away from the firms, or that some sectors with a small amount of commuting (e.g. agriculture) have been declining, while other sectors with large commuting distances have been growing. The goal in this paper is to measure different factors explaining the change in the amount of commuting. This is done by a decomposition analysis, a method described below. One of the factors is the location of sectors. The changed location pattern of Danish firms is analysed in Jensen et al. (1997). Here it is concluded, that since 1980 there has been a decentralisation of places of work to municipalities with more than 10,000 inhabitants. In the smallest municipalities employment has decreased. The pattern differs, however, dependent on the sector. The number of places of work in manufacturing has increased in rural municipalities, while in general the number of places of work has increased in cities.

The decomposition method

The change in a variable over a period of time can be analysed by looking at the changes in factors determining the variable. This is what is done in a decomposition analysis. The contributions from different factors are measured. The general approach is to "split an identity into its components". The splitting should secure *mutually exclusive* and *completely exhaustive* terms (Rose and Casler, 1996), that is, the contributions from the factors should be completely separated, and they should sum up to the correct amount. These requirements are not satisfied by all decomposition methods, however, as discussed below.

The objective in this paper is to decompose the change in the amount of commuting between the Danish municipalities between 1980 and 1995. The data mainly stem from the LINE model, which is a macroeconomic model at the municipality level for Denmark built up at AKF, Institute of Local Government Studies – Denmark. The model for commuting as used in this paper includes the number of employed and their place of residence, places of work and sector. As later described in detail the change in the amount of commuting is decomposed into changes in the total number of employed, changes in sector distribution and changes in sector location as well as commuting pattern.

The point in decomposition analysis is to describe the change in a variable as a result of changes in different factors describing the variable. To illustrate, a simple example is described.

Let y be the variable which is to be decomposed. Assume

$$y = abc \qquad \textbf{(1)}$$

that is, y is the product of three factors, a, b and c. The factors are either scalars or matrices. If the factors are matrices, the product can be either matrix multiplication or element by element multiplication. Since it is the change which is to be decomposed, two different points in time are considered. Let y_0 refer to the earliest point in time and let y_1 refer to the latest. Similarly for the factors.

Now, look at the change in the variable, that is:

$$y_1 - y_0 = a_1 b_1 c_1 - a_0 b_0 c_0 \qquad \textbf{(2)}$$

Different decompositions are possible. It is possible to obtain:

$$\begin{aligned} y_1 - y_0 &= a_1 b_1 c_1 - a_0 b_0 c_0 \\ &= (a_1 - a_0) b_0 c_0 + a_1 (b_1 - b_0) c_0 + a_1 b_1 (c_1 - c_0) \end{aligned} \tag{3}$$

Another possible decomposition is:

$$\begin{aligned} y_1 - y_0 &= a_1 b_1 c_1 - a_0 b_0 c_0 \\ &= (a_1 - a_0) b_1 c_1 + a_0 (b_1 - b_0) c_1 + a_0 b_0 (c_1 - c_0) \end{aligned} \tag{4}$$

These two expressions share the fact that it is factor *b* which is weighted with one factor from the early period and one from the late. In order to choose between the two above stated expressions, both Fujimagari (1989) and Sawyer (1993) decide *not* to choose, and instead use a simple average. By this, the expression becomes:

$$y_1 - y_0 = \frac{(a_1 - a_0) b_0 c_0 + (a_1 - a_0) b_1 c_1}{2} + \frac{a_1 (b_1 - b_0) c_0 + a_0 (b_1 - b_0) c_1}{2} + \frac{a_1 b_1 (c_1 - c_0) + a_0 b_0 (c_1 - c_0)}{2} \tag{5}$$

The approaches represented by equation (3), (4) and (5) respectively, are all completely exhaustive, i.e. the factors sum up to the right amount.

As another alternative Wier (1998) uses this expression:

$$y_1 - y_0 \approx \frac{(a_1 - a_0) b_0 c_0 + (a_1 - a_0) b_1 c_1}{2} + \frac{a_0 (b_1 - b_0) c_0 + a_1 (b_1 - b_0) c_1}{2} + \frac{a_1 b_1 (c_1 - c_0) + a_0 b_0 (c_1 - c_0)}{2} \tag{6}$$

In this expression all the terms are weighted as the first and last term in the above expression. By this the decomposition becomes independent of the order of the factors, which is a nice characteristic, since it can be difficult to argue for a specific order. Unfortunately, the terms do not sum up to the left-hand side anymore. Anyway, in Wier (1998) there is no indication of numerically problems.

Madsen and Caspersen (1998) use two different approaches. The first is denoted *cumulative* and corresponds to (3) above, while the second is denoted *isolated*. In that, only one of the factors is changed to the value in the last year, while the rest is kept at the original level. It corresponds to half the expression (6) above, i.e.:

$$y_1 - y_0 \approx (a_1 - a_0) b_0 c_0 + a_0 (b_1 - b_0) c_0 + a_0 b_0 (c_1 - c_0) \tag{7}$$

The terms do not sum to the left-hand side, as illustrated numerically in Madsen and Caspersen (1998). The results are instead interpreted as isolated multiplicator calculations. Lakshmanan and Han (1997) give a related alternative. They weight all the factors in the same way, but in order to secure that the decomposition is exhaustive, i.e. that the elements sum up to the correct amount, they denote the residual as an interaction term. By using this approach, the interpretation becomes very straightforward: the first terms indicate the effect from the different factors – given that the other factors are not changed, while the last term captures the effect from the interaction of the factors. By putting the four different interaction effects together there is a risk, however, that this term becomes too big, with the possibility of losing information.

To illustrate the consequences of choice of method, the expressions (3), (4), (5), (6) and (7) are all used in this analysis.

Model formulation

The analysis starts with total employment. The employment numbers exist, however, for every pair of residence and place of work location for every sector. By using quotients the total employment is distributed according to these characteristics, one by one. First it is distributed to sectors, secondly to sectors and places of production, and thirdly to sectors, places of production and residence location. This is the most detailed level for the data. But afterwards the sector specification is eliminated in order to reach only one matrix of interaction between the municipalities, since the distance between municipalities is unaffected by the sector. At last, this matrix is multiplied, element by element to the distance matrix, and all elements are summed up. The inclusion of the distances can be seen as a way to weight the different commuting patterns.

Let *q* be the amount of employment, while *e* denotes the sector, *a* the place of working and *b* the place of residence. *Q* denotes a quotient. By that, Q_e distributes employment to sectors, Q_{ae} distributes the employment to place of work too, while Q_{bae} distributes employment to place of residence too. Let c_{ab} be a matrix of distances between municipalities, and let *C* be the amount of commuting. The model can be written by:

$$C = \sum_b \sum_a (c_{ba} \cdot (\sum_e (Q_{bae} \cdot (Q_{ae} \cdot (Q_e \cdot q))))) \quad \textbf{(8)}$$

This equation corresponds to *y=abc* in section 2 of this paper. The only difference is the number of factors. Here there are five factors, but since the distance matrix is assumed constant during the period, only four factors are considered. The decomposition methods, as described earlier, can be directly applied to this equation.

Behind the model there is an underlying hypothesis – i.e. arguments for including the specific factors, and the order of them. Even though it is given that total employment is to be distributed to sector, place of work and place of residence, it is not given in which order this is going to happen. The order influences the definition of the quotients, which are the factors that the decomposition is actually carried out for. The different contributions to the amount of commuting are contributions due to changes in the quotients – which represent changes in the behaviour of individuals or the structure of the economy.

Here, the model is demand driven. It is assumed that exogenous demand for production gives rise to total employment. It is also assumed, that the exogenous demand for production determines the distribution of employment into sectors. Next it is assumed that the sectors locate due to a specific pattern, giving rise to a geographical distribution of the sectors. At last it is assumed, that individuals working in specific sectors in specific municipalities locate in specific municipalities.

This causality corresponds to Keynesian theory, and by that to the causality in the existing LINE model. It is the demand for goods which pulls the economy, and which determines the sector distribution. Furthermore, firms in sectors locate in order to satisfy this demand, and individuals locate in order to satisfy the demand for labour from the firms.

The decomposition is model dependent. By defining another model different results would come up. The model could be defined in accordance with neoclassical growth theory. Here, growth in the economy is determined by supply of capital and labour. The relevant model in this case would partly retain the order of factors: It is still assumed that the number of employees is determined exogenously, and that the distribution by sectors is given exogenously, too. But then it is assumed that individuals in sectors locate according to a given pattern, and at last it is assumed that firms locate relatively to the supply of the workforce. The resulting model would be given by:

$$C = \sum_b \sum_a (c_{ba} \cdot (\sum_e (Q_{abe} \cdot (Q_{be} \cdot (Q_e \cdot q))))) \qquad \textbf{(9)}$$

using changed quotients.

To illustrate the importance of the model formulation, a decomposition is carried out for this model as well.

Data

The interaction between place of production and place of residence is analysed. The data stem from LINE, the macro economic model at municipal level for Denmark built up at AKF, Institute of Local Government Studies – Denmark. There are 275 municipalities in Denmark. The number of sectors is 12. The sectors are listed in table 2.

Table 2. Sectors in the analysis

1	Primary sectors	7	Hotels and entertainments
2	Manufacturing industry	8	Transport
3	Other industry, utilities	9	Private service, finance
4	Construction	10	Other private service
5	Wholesaling	11	Hospitals, higher education
6	Retailing	12	Other public services

The data exist for 1980, 1987 and 1995. For each year the data consist of 12 place of work-residence matrices (one for each sector) of dimension 275 times 275, containing the number of individuals working in that specific sector in a specific municipality and living in another municipality.

The basis for the LINE data is the *RAS*-register, Statistics Denmark. The number of employed according to place of residence, place of work and sector is observed in November. The entire Danish workforce is covered. For some individuals the place of work is not registered. To be able to include these people in the analysis, the places of work for this group are assumed to follow the same pattern as individuals living in the same places and working in the same sectors, in the specific year. The group is large in 1980, but small in 1995, reflecting increasing data quality.

It is not the actual number of trips which is modelled, but the employees. There is no information about how often people actually commute. Despite this, the matrix showing the interaction between the different municipalities will be used as an approximation for the actual commuting. The interaction matrix multiplied with the distances between different municipalities is used in order to find an amount of total commuting, as shown in table 1.

The distances stem from Vejdirektoratet (1994). Since data only exist for a single year, the distance matrix is held constant in the decomposition. It has to be chosen how the ferry routes are to be treated, since Denmark consists of a lot of islands, and the distances from Vejdirektoratet (1994) only are by land. Here, the distances by sea are simply set to the actual distance (measured in kilometres). A computer programme made by Erik Kristiansen, AKF, examines the different possible routes between municipalities in different parts of the country, and chooses the shortest one. Distances within municipalities are approximated by 0.66 times the radius of a circle of a similar area.

The resulting unit for the amount of commuting is kilometres. The amount of commuting can be interpreted as the distance the entire labour force moves in one day in order to go to work. In order to include the trip from work to home, all distances just have to be multiplied by two. The problem concerning trip frequency has to be remembered, however.

Results

Since the distances between municipalities are assumed constant during time, there is no contribution from this factor in the decomposition, and the factor is omitted from the analysis.

The results from the decomposition using the different methods are shown in table 3.

Table 3. Decomposition of change in amount of commuting, 1980-1995, using different approaches

		Level of employment	Sector distribution effect	Sector loca-tion effect	Commuting pattern effect	Residual	Total
F & S	1000 Km	1,257	188	92	6,897	-	8,434
(Eq. 5)	%	14.9	2.2	1.1	81.8	-	100
Eq.(3)	1000 km	1,378	265	771	6,021	-	8,434
	%	16.3	3.1	9.1	71.4	-	100
Eq.(4)	1000 km	1,136	112	-586	7,772	-	8,434
	%	13.5	1.3	-6.9	92.2	-	100
Wier	1000 km	1,257	191	178	6,897	-88	8,434
(Eq. 6)	%	14.9	2.3	2.1	81.8	-1.0	100
Isolated	1000 km	1,136	109	-449	6,021	1,617	8,434
(Eq. 7)	%	13.5	1.3	-5.0	71.4	18.8	100

It is seen that due to the approach used by Fujimagi (1989) and Sawyer (1992), the commuting pattern effect is the biggest contribution, responsible for 81.8% of the increase in the amount of commuting. Next follows growth of employment, responsible for 14.9% of the increase. The sector distribution and the sector location have also had positive effects on the increased amount of commuting, but very small.

As described earlier, the approach by Fujimagari (1989) and Sawyer (1992) is the average of two different decompositions. The contributions are averages of two different numbers, since the change in the specific variable is weighted in two ways. In table 3 the two different decompositions are denoted eq. (3) and eq. (4) respectively. From the results, it is obvious that the weighting influences the result – the sector location effect gives a positive and a negative result respectively. The other contributions differ as well. Since it is hard to argue which alternative is the most reasonable, the approach used by Fujimagari (1989) and Sawyer (1992), taking an average, seems to be reasonable.

Another alternative, however, is to use the approach described in Wier (1998). The result using this method is also shown in table 3. As argued earlier, this method does not secure that the different effects sum up to the total change. Here the difference is 1%. The level of employment effect and the commuting pattern effect are by definition the same as in the approach used by Fujimagari and Sawyer (since it is the first and the last part of the model). Besides, the sector distribution effect has only changed slightly, while the sector location effect has changed from 1.1% of total change to 2.1%, still insignificantly small numbers. As discussed in Andersen (1998), the results from the two approaches are also rather similar for decompositions carried out for two sub-periods, even though the contributions in the middle of the model are bigger here. So for this model, the two different approaches all in all yield an only slightly changed result.

When interpreting the results, it is necessary to remember the comments given earlier. Here it was stated that the order of the elements influences the result, i.e. the decomposition is model dependent. The causality in the model is, as described earlier, that an exogenous increase in employment is sector dependent. These sectors are located in different municipalities, and individuals working in these sectors in these municipalities are located in specific municipalities. The contributions from the different factors measured in the decomposition must be interpreted due to this causality.

The contribution from the level of employment is exogenous. Given some average sector distribution, the geographical distribution of the sectors and the commuting pattern the changed level of employment gives rise to this amount of commuting. Next, the contribution from sector distribution can be interpreted as the amount of commuting due to a changed sector distribution, where some average level of employment, some average geographical distribution of the sectors and some average commuting pattern are assumed. Thirdly, the contribution from sector location is the amount of commuting due to a changed location of sectors, given that the level of employment, the distribution of sectors and the commuting pattern are average. At last, the contribution due to the commuting pattern is the amount of commuting due to a changed commuting pattern, given some average level of employment, the sector distribution and the location of sectors.

Since the model states that the sectors have a specific location pattern, and the individuals then locate, it is not possible to tell whether firms have moved away from individuals, or individuals have moved away from firms when the amount of commuting increases due to a larger distance between firm and residence. It also covers the case where individuals choose another job for a given residence. In the model, it is simply assumed that individuals locate relative to their employment place. For the alternative model, a decomposition is carried out at the end of this section.

The *isolated* approach used by Madsen and Caspersen (1998) corresponds to single multiplicator experiments. The result using this method is shown in the last row of table 3.
All the factors are smaller than in the Fujimagari and Sawyer approach, as well as in the approach by Wier. The residual, or the interaction effect as it is denoted by Lakshmanan and Han (1997), is rather big. It is rather easy to interpret the first four contributions, since it is the contributions due to a change in the specific variable, given that the values of the other factors have not changed from the initial level. The interaction effect is, however, difficult to interpret. It can only be judged that it is an effect due to interaction between the changes in the variables.

In general, it is seen that the level of employment effect and the sector distribution effect have the same order of magnitude in all approaches. The sector location effect, on the other hand, appears to be both positive and negative. All contributions are relatively small, however. The commuting pattern effect varies from 71.4% to 92.2%, quite a difference, but still a significant contribution in all approaches. As noted above, the decompositions carried out using the Fujimagari and Sawyer approach and the Wier approach give approximately the same results. The isolated approach is more different from these two approaches, having a rather big residual or interaction effect.

Since data exist for 1987 too, it is possible to carry out decompositions for two sub-periods. The results are described in Andersen (1998).

An alternative model formulation

As described in section 3 the model can be formulated alternatively, by changing the order of the last two factors. The result of a decomposition of this model is shown in table 4.

Table 4. Decomposition of change in the amount of commuting, 1980-1995, using the Fujimagari and Sawyer approach (eq. (5)), at the alternative model formulation (eq. (9))

	Level of employment	Sector distribution effect	Individuals location effect	Place of work location effect	Total
1000 km	1,257	189	730	6,258	8,434
%	14.9	2.2	8.7	74.2	100

It is seen that this model gives rise to a rather different result. Here, it is the place of work location effect which dominates and is responsible for a big part of the increased commuting. This result emphasizes that the factor contributions should be interpreted with care, since the results vary a lot for different assumptions. Still, however, it is the commuting pattern which is responsible for a big part of the increased commuting. It is simply not possible to say whether the firms or the individuals are responsible.

Conclusion

The change in the amount of commuting, measured as the distance the entire Danish workforce has to travel to go from their residence to their job, has been decomposed. Different decomposition methods have been presented and applied. The different methods give rise to partly different results, but in general the contributions have the same order of magnitude. It is difficult to argue for one specific method, since the methods have different good and bad characteristics, and none is perfect. The Fujimagari and Sawyer approach gives a *completely exhaustive* splitting, using average weights, which seems very reasonable. The interpretation of the different terms is not very straightforward, however. On the other hand, the isolated approach, used by Madsen and Caspersen (1998) as well as Lakshaman and Han (1997) gives *mutually exclusive* terms, which are very easy to interpret. Unfortunately, the decomposition is not exhaustive. A general conclusion would be that when using a specific decomposition technique, only the order of magnitude of the results should be counted on, since using another technique would give rise to slightly changed numbers.

The amount of commuting is determined by several factors, given by a model. The model is based on Keynesian theory, where demand for goods determines the growth in an economy, as well as the sector distribution and sector location, and individuals locate relative to this. The resulting contributions should be interpreted with this model in mind. An alternative model is formulated, based on neoclassical growth theory. Here, the supply of labour and capital determine the growth in the economy and the sector distribution. The location of individuals is an exogenous factor, as is the location pattern of firms, relative to the location of individuals.

The general result from the different decompositions is that changes in the commuting pattern are responsible for a big share of the increased commuting. Due to the Keynesian model, it is the location of individuals further away from the places of work which has caused the increased commuting. Due to the neoclassical model, however, it is the location of firms further away from the individuals which is responsible. With existing data it is not possible to judge which case is the true one. It is only given that it is the changed location pattern which is responsible. The number of employed people is responsible for part of the increased commuting, too. The sector distribution, on the other hand, is only responsible for a very small part. In the Keynesian model, the sector location effect gives rise to rather small negative or positive contributions, dependent on the decomposition method used. In the neoclassical model, the residence effect gives rise to a somewhat bigger amount.

The policy implication of the decompositions is that the changed location pattern is important. The increased amount of traffic is only partly directly due to growth in the economy, i.e. the increased number of employed people. To constrain the amount of traffic, it is essential to constrain the location pattern. There exist many possible reasons for the changed commuting pattern. The costs of transport have decreased relatively in the period. The improved infrastructure makes it easier to live further away from a place of work. The workforce has become more specialized, making it more difficult to find a relevant job nearby. This effect combined with the fact that in many households there are two employed people, makes it difficult to avoid commuting. Furthermore, the decentralisation of firms away from big cities can have increased the commuting. It is not possible, with this analysis, to judge which reasons are the true ones.

By combining the decomposition analysis with data for trip frequencies and modal split, it would be possible to analyse the actual amount of traffic, instead of only the amount of commuting as defined in this paper. It would add some factors to the decomposition and be relevant according to environmental problems caused by traffic. Furthermore, a division of the data on different groups, i.e. male and female, age groups, education groups etc. would give the possibility of separate decompositions for these groups. It would possibly give rise to substantial differences. Another possibility is to carry out the decompositions for different parts of Denmark, to reveal spatial differences.

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Notes

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2.The number for 1981 is encumbered with uncertainty, since it is rounded. It means that the average commuting distance in 1981 was between 10.5 and 11.4 km, giving rise to a growth in commuting between 26 and 37% (see Carl Bro (1997)).