E.ON Energy Research Center
FCN | Institute for Future Energy Consumer Needs and Behavior

FCN Working Paper No. 9/2014

Determinants of Commuter Trends and Implications for Indirect Rebound Effects: A Case Study of Germany's Largest Federal State of NRW, 1994-2013

Raymond Galvin and Reinhard Madlener

September 2014

Institute for Future Energy Consumer Needs and Behavior (FCN)

School of Business and Economics / E.ON ERC

RWTH AACHEN UNIVERSITY

FCN Working Paper No. 9/2014

Determinants of Commuter Trends and Implications for Indirect Rebound Effects: A Case Study of Germany's Largest Federal State of NRW, 1994-2013

September 2014

Authors' addresses:

Raymond Galvin, Reinhard Madlener
Institute for Future Energy Consumer Needs and Behavior (FCN)
School of Business and Economics / E.ON Energy Research Center
RWTH Aachen University
Mathieustrasse 10
52074 Aachen, Germany
E-mail: RGalvin@eonerc.rwth-aachen.de, RMadlener@eonerc.rwth-aachen.de

Publisher: Prof. Dr. Reinhard Madlener
Chair of Energy Economics and Management
Director, Institute for Future Energy Consumer Needs and Behavior (FCN)
E.ON Energy Research Center (E.ON ERC)
RWTH Aachen University
Mathieustrasse 10, 52074 Aachen, Germany
Phone: +49 (0) 241-80 49820
Fax: +49 (0) 241-80 49829
Web: www.eonerc.rwth-aachen.de/fcn
E-mail: post_fcn@eonerc.rwth-aachen.de

Determinants of Commuter Trends and Implications for Indirect Rebound Effects: A Case Study of Germany's Largest Federal State of NRW, 1994–2013

Ray Galvin* and Reinhard Madlener

Institute for Future Consumer Energy Needs and Behavior (FCN), School of Business and Economics / E.ON Energy Research Center, RWTH Aachen University, Mathieustr 10, 52074 Aachen, Germany

September 2014

Abstract

Home-work commuting distances are increasing in Europe. Many studies see this as due to geographical mismatches between workplaces and homes, or worker skills and job locations, and often recommend policies to close geographical gaps between jobs and suitable workers. A different approach sees commuting as essential in a modern economy, as it facilitates information flow across complex economic networks in geographically dispersed regions. In this 'city-network' view, many workers make deliberate choices to commute and many employers encourage this. This paper explores these viewpoints in a case study of increasing commuting in Germany's most populous state, North-Rhine-Westphalia, in 1994-2013, using Federal data on workers' home and work locations. It finds an average annual increase in commuter numbers of 1.35%, from 43% to 55% of the workforce. Some of this increase can be explained by worker skills and job location mismatches, but steady increases in various commuting metrics lead to the suggestion that commuting is also something people choose to do. This supports the city-network hypothesis, and also implies a rebound effect of increased travel due to increased economy-wide energy efficiency. Qualitative and quantitative studies are needed to identify the actual reasons people commute, and to more accurately estimate rebound effects.

Keywords: Commuting; city networks; rebound effect

* Corresponding author. Email: rgalvin@eonerc.rwth-aachen.de (R. Galvin)

1. Introduction

This paper explores the extent to which the geographical disparity between workers' home location and the location of available work determine commuter numbers, using Germany's largest state, North Rhine-Westphalia (NRW), as a case study. It quantifies this determinant over the period 1994-2013 for NRW, and enhances this analysis by comparing features of NRW commuting to those of other similar and dissimilar German states. On the basis of the results it makes suggestions for further research on the remaining determinants of commuter numbers.

Increasing distance and duration have been a world-wide feature of travel to work over the last decades, with total daily commute times of 45 minutes or more now typical in developed countries (Thomas and Tutert, 2013). There is concern internationally to reduce fuel consumption and CO*2* emissions. However, energy consumption and CO_2 emissions in transport are increasing more rapidly than in any other sector in Europe, showing a 20% increase in fuel consumption and 12% increase in CO2 emissions in 1997-2007 (Eurostat, 2009). This represented 20% of Europe's CO_2 emissions in 2007. Further, since transport is largely a functional element within the wider economy, commuters' increasing energy consumption in an environment of steadily improving economy-wide energy efficiency indicates the possibility of strong 'rebound effects' (Khazzoom, 1980; Berkhout et al., 2000; Sorrell and Dimitropoulos, 2008). Rebound effects mean that only a portion of the gains through energy efficiency improvements actually go to reducing energy consumption. The remaining portion is 'taken back' through increasing consumption of energy services, such as km traveled or tonne-km transported.

It is frequently suggested that a major determinant of increased commuting is increasing spatial disparity between centres of employment and centers of residence. Axisa et al. (2012) find this a main determinant of commute distance in Toronto, Canada. Suburbs built since the Second World War 'are located farther from central cities and occupy significantly larger areas than those built prior to the war' (*op. cit*.: 123), hence more people live further from their place of work. Similarly, Buchanan et al. (2006) find increasing residential development on the outer fringe of Christchurch, New Zealand, led to greater commuting distances. For the United States, Modarres (2013) summarises research which points to the spatial disparity between residential and work districts, together with dependence on private cars, as the main causes of heavy fuel consumption in commuting. He notes the strong commitment among researchers to the 'density solution', which posits that building more homes close to job-rich areas would reduce commuting and therefore fuel consumption. He notes, however, that this view has been challenged. For example, Mindali et al. (2004) find increasing the population density of UK cities does not necessarily reduce commuting fuel consumption.

While urban areas in Europe tend to be more compact than those in North American and Australasia, there are comparable tendencies of suburban expansion. García-Palomares (2010) finds commuting distances have increased due to increasing urban sprawl around Madrid, Spain. Travisi et al. (2010) find similar tendencies in seven geographically distinct districts in Italy, but also note the tendency for firms, too, to relocate from cities to previously rural areas. Hence some citywide travel to work is replaced with rural travel that may or may not involve longer distances.

House prices and availability also seem to have an effect on commuting distances. Adair et al. (2000) found house prices in some districts in Belfast were influenced by accessibility of routes into the Central Business District. Boussauw and Witlox (2009) found the 'rigidity of the housing market' in Flanders, Belgium was a major contributor to commuting distance, as it strongly compromised people's ability to live near their place of work. Brueckner (2000) found US house prices often correlated with accessibility to work, but calculated that increased commuting costs and poor transport infrastructure often more than offset the housing savings of living outside the city

Municipal research centres in Europe often see a strong connection between commuting distance and the location of residential districts. In its 2008 report on commuting in the German state of Baden-Württemberg, the state's Statistics Office (Statistisches Landesamt Baden-Württemberg) suggests that suburbanizing trends are a major factor in the steady increase in commuting throughout the state (Winkelmann, 2008). In recent years, it notes, more and more people have moved to live in 'green' districts outside the city, and jobs are far more strongly spatially concentrated throughout the state than are residential areas. A similar conclusion is drawn in commuting analyses by the Chambers of Commerce in the state of NRW (Drews and Frohn, 2011). It suggests one of the major determinants of the steady increase in commuting in NRW is the 'suburbanization tendency, which increases the divergence between work and residence'.

A question which emerges from these studies is whether the magnitude and increase in commuting are caused by these shortages of accommodation in job-rich areas, or whether there are additional or alternative determinants. Is it that people want to live near their work but are prevented from doing so, or do other factors cause them to work increasing distances from where they live? This question is important for policymakers because of calls to solve the commuting problem by improving the 'job-housing balance' (Modarres, 2013; Verhetsel and Vanelslander, 2010), for example by increasing urban residential density in employment-rich areas.

The theme of the job-housing balance also emerges in studies on the influence of parenting and gender on commuting. In Sweden, Cassel et al. (2013) found willingness to commute long distances strongly associated with having children in a household, due to the desire not to relocate. Wachs et al. (1993) found Californian households with children commuted shorter distances, due to household responsibilities. McQuaid and Chen (2012) found UK men commute longer than women, with fathers commuting the greatest distances and mothers the least. McQuaid et al. (2001) found UK job-seeking women with children were less willing to commute. Crane and Takahashi (2009) found that men in the US commuted longer than women even when neither were parents, but that distances were converging, especially for younger workers. In a similar vein, Green (1997) found dual person households more likely to commute longer distances, as it is harder to find suitable jobs for each in the same district.

A theme of such findings is that workers want to live near their workplace but may be prevented from doing so by social or demographic factors. The jobs are in the wrong locations for the workers. In this paper this is called the 'jobs-homes hypothesis'.

Educational level has also been positively correlated with commuting distance (Cassel et al., 2013; Green et al., 1999; Sandow, 2008). Thomas et al. (2013) found an average commuting distance in the Netherlands in 2006 of 24.0km among highly educated workers, 18.7 km among middle-educated, and 16.4km among lower educated. Cassel (2013) suggests the willingness of more highly educated people in Sweden to commute longer distances is related to their earning higher wages, which reduce the relative cost of commuting. In a further Swedish study, Sandow (2008) concludes that the more highly educated are forced to seek suitable employment over a wider area due to their specialization of skills.

An underlying theme in these studies is that commuting is to some extent determined by a geographical mismatch between jobs, homes and worker skills. In this paper this is called the 'jobs-homes-skills hypothesis'.

A different way of framing commuting is to set it within the increasing complexity, diversity and interdependence of modern knowledge-based industry. Reggiani et al. (2011) suggest such industry functions within a 'city network'. A city network is an economically dynamic region encompassing multiple population and enterprise centres, with constant interactions between economically relevant sectors such as transport, manufacturing, research and development, administration, logistics, information services, energy production, governance services and human resources. One of its most important features is innovation, so that its products and services remain competitive and relevant to markets.

Reggiani and colleagues identify 17 cities in Germany as nodes in city networks which together account for 67% of national GDP. Five are in NRW (Bonn, Dortmund, Düsseldorf, Essen and Cologne) and their commuter catchment areas cover most of NRW.

A key element in a city network is knowledge, and especially its flow between nodes within the network, and to and from other networks. Drawing on Glaser et al. (1992), Reggiani and colleagues note that knowledge flows 'are more effective where communication between people is more effective' (p.530). To make knowledge accessible and mobile, there need to be movements among people, because 'exchanges of labour may bring about changes in knowledge commuting flows' (p.529). Commuting is the main everyday facilitator of such movements, and Reggiani and colleagues suggest it so closely approximates the flow of knowledge that the degree of commuting can serve as a proxy for these knowledge flows.

Therefore, labour markets ‘are not isolated markets that are only connected to local activity. They form a network of interconnected markets that influence each other’ (p.528), and this happens through commuting flows.

Seen through this framework, commuting is not a fault to be remedied, but an essential social-economic function serving to bind a city network together and enrich it with vital information flows. In city networks there are large rewards for workers who can bring the skills and information that trigger continuous, large-scale innovation, while their employers and the wider economy also benefit.

An important question, then, is: do workers commute because they *have* to, due to jobs-home and jobs-home-skills mismatches, or do they *prefer* to because of inherent advantages of commuting, which may be related to (what is called in this paper) the ‘city network hypothesis’?

A first step in addressing this question is to see whether there is, in fact, a geographical mismatch between numbers of jobs and numbers of homes. Due to the detailed nature of labour market statistics in Germany, it is possible to explore this question at a high degree of precision. A second step is to see whether these statistics allow conclusions about jobs-homes-skills mismatches to be drawn. If some but not all of the commuting patterns can be explained by the jobs-homes and jobs-homes-skills hypotheses, it can then be asked whether the data suggests residual commuting could be explained by the city-network hypothesis.

The remainder of this paper proceeds as follows. Section 2 gives a brief overview of relevant economic and labour factors in NRW, and introduces the data sources. Section 3 shows the changes in numbers of commuters in NRW in 1994-2013, including relevant comparisons with other German states. Section 4 conducts a further analysis to evaluate evidence for mismatches in jobs, housing and skills, inasmuch as the data available can indicate this. The findings are discussed in Section 5, and Section 6 offers conclusions and recommendations for further study.

2. North-Rhine-Westphalia and statistics

2.1 North-Rhine-Westphalia

NRW is Germany’s most populous state, with 17,554,000 inhabitants in December 2012, or 21.80% of Germany’s 80,524,000 (Destatis, 2014a). With a land area of 34,092 km^2 (Destatis, 2012) NRW comprises 9.55% of Germany’s area and has a population density of 515 persons per km^2.

NRW’s GDP, at €568.9 billion, made up 22.1% of Germany’s GDP of €2570.8 billion in 2011 (Destatis, 2012). With a GDP per capita of €31,893 NRW is close to the German average of €31,440. This puts NRW ahead of its southern neighbouring states Rhineland-Palatinate (€28,311) and Saarland (€30,059) and its northern neighbor-but-one Schlieswig-Holstein (€25,967), but behind its eastern neighbour Hessen (€37,616), which contains the banking centre Frankfurt. NRW also has lower GDP per capita than the two other economically powerful western German states of similar land area but smaller population, Bavaria (€35,545) and Baden-Württemberg (€34,943).

Unlike these two states, NRW has been undergoing a process of economic transition from heavy industry toward a high-technology and service economy over the past 50 years (Maggi, 2000). Heavy industry was never a prominent feature of the economies of Bavaria and Baden-Württemberg.

An indication of the pace of this transition in NRW is illustrated in Figure 1. The output of the ‘service industry’ – a loose term covering almost all industry-related activities apart from manufacturing and farming – grew by 48% in 1993-2012 in nominal terms while production industry contracted slightly[1]. Hence the (nominal) growth in total economic output, of 26.7%, was largely driven by the service industry (IT-NRW, 2012). Figure 1 also reflects the economic cycle, including a steep fall in production output in 2008 associated with the economic crisis, though only a small downturn in services output at that time.

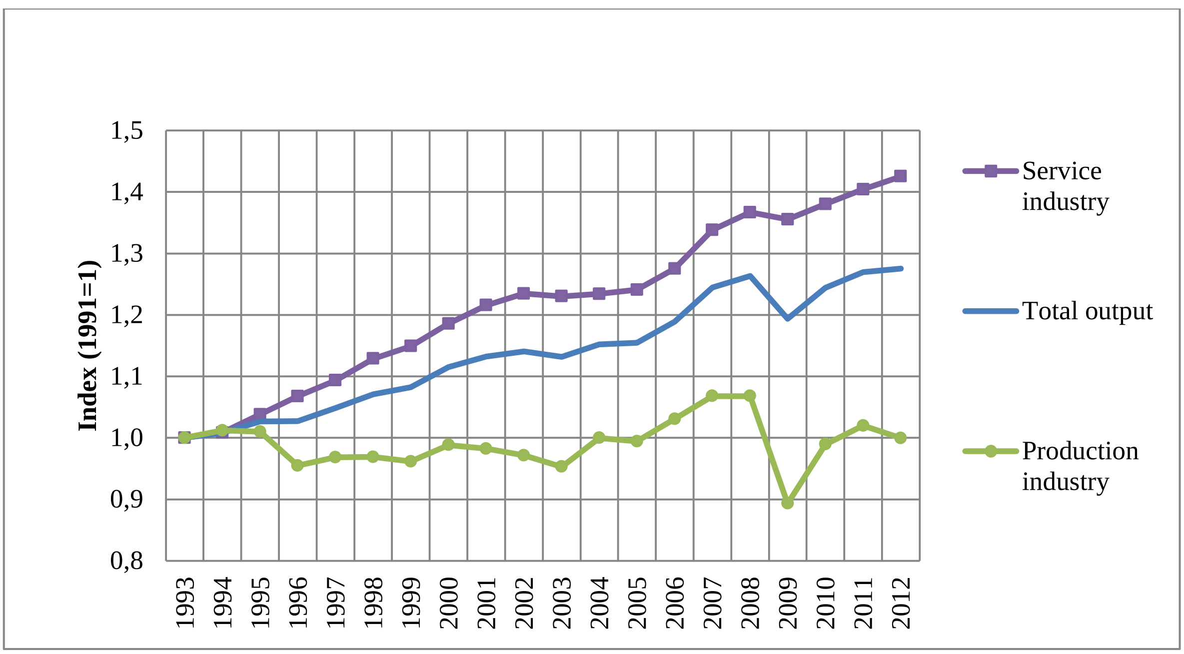

Figure 1: Change in (nominal) economic output of NRW industry classes 1993-2012 indexed (1993=1). Data source: IT-NRW (2012)

The magnitude of this transition is sometimes seen as a likely cause of the increase in commuting in NRW, since high-technology workplaces are not necessarily established on the sites cleared by abandoned factories (e.g. Drewes and Frohn, 2011).

NRW lies at the western edge of Germany and borders Belgium and the Netherlands, which are also high-density population regions with strong industrial and commercial infrastructures.

[1] These figures were not available for 2013, the final year of this commuting analysis.

2.2. Commuter statistics and NRW

This paper considers all commuters regardless of mode of transport. Germany does not record vehicle mileage for annual car re-registration, and there are no detailed records of distance traveled by the private motoring fleet. Regular household surveys such as the German Mobility Panel (MOP, 2011) ask respondents for employment and car travel data, though the latter suffers inaccuracies of reporting (Frondel et al., 2012). Further, statistics on modal split in commuting are available only from localized studies based on approximately random selection (e.g. Drews and Frohn, 2011).

However, Germany's Federal Agency for Labour (Bundesagentur für Arbeit, BA - http://www.arbeitsagentur.de/) gathers precise data on numbers of commuters throughout Germany as on 30 June each year. Four key parameters are recorded and published for each of Germany's 13,271 'statistical districts'. A statistical district usually corresponds to a local political district, but not necessarily. NRW has 396 such districts (well below the state-by-state average of 829), giving an average of 44,328 persons and 86.1 km^2 per district, but these vary considerably from district to district. The most populous statistical district in NRW is the city of Cologne, with 1,024,373 inhabitants, while the least populous is Dahlem, with 4,116. The average distance between the geographical centres of each district is 10.2 km, so that the average surface travel distance between any two points in adjacent districts is approximately 14 km (Drews and Frohn, 2011).

The raw data is in the form of numbers of 'regular workers', or '*Sozialversicherungspflichtig Beschäftigte*'. These are people who are currently employed and thereby required to pay social insurance tax. This excludes self-employed and '*Beamte*', a class of civil servant who are guaranteed an income for life. In 2013 there were 29,145,011 regular workers in Germany, 1,694,215 *Beamte*, and approximately 581,000 self-employed (Statistika, 2014a). In NRW there were 254,475 *Beamte* in 2011 (NRW, 2012: figures for 2013 not available), approximately 122,000 self-employed, and 5,876,380 regular workers. Hence non-regular workers, who are excluded from the Labour Agency statistics, make up approximately 6% of the NRW workforce. This introduces a degree of error into our analysis, but as this shortfall is consistent in the statistics across the years of analysis, it was decided to exclude these non-regular workers from the study.

The four key parameters in the data for each district are:

1. *'Wohnort'*: the number of workers who *live* and *sleep* in that district, regardless of where they work. (represented here by the variable ***W*** ('workers')).
2. *'Arbeitsort'*: the number of jobs in that district, regardless of where the workers who have these jobs live. (variable ***J*** ('jobs'))
3. *'Einpendler'* ('in-commuters): the number of workers who commute *into* that district (variable ***I***)
4. *'Auspendler'* ('out-commuters': the number of workers who commute *out of* that district to work somewhere else (variable ***U***, since 'O' would be confused with zero)

The data gives 1,061,680 data points over the 20 years 1994-2013, including 31,680 for NRW. In most states some data points for small population centres are missing, but all data points are given for NRW for all years. Further, in some states there were district boundary agglomerations in 2010, making parts of analysis difficult for these states and for Germany as a whole, but in NRW the boundaries were consistent throughout. There are also datasets which give the numbers of in-commuters commuting from each district to each other district, making approximately 25 million data points, but these were not used as sufficient information could be obtained from the smaller dataset for this analysis. However, an edited version of the larger dataset for 2012 (IT-NRW, 2013) was referred to where required for more precise information.

Each statistical district in Germany has an eight-digit identifier. The first two digits indicate which state the district is in, making it easy to extract state-by-state data electronically. The data is arranged regionally and sub-regionally, with summary statistics inserted after each sub-region's and region's statistics. These have to be expunged to avoid double-counting, a process facilitated by the use of six- and four-digit identifiers for sub-regions and regions within states.

There is always a small difference between the statewide total of workers *W* living in districts and the statewide total of jobs *J* in districts, because of differences in commuting numbers into and out of the state. In NRW the net daily gain from outside the state amounts to 1.6%, including a statistically negligible 0.075% from Belgium is (4,504 in-commuters) and 0.081% from the Netherlands (4,817 in-commuters).

For the purposes of this paper, a 'commuter' is a worker who crosses at least one district boundary in travelling from home to work, while a 'non-commuter' is one who lives and works within the same district. The paper does not explore changes in commuting distances, but rather changes in the numbers of workers who are or are not commuters according to this definition. This enables changes in commuting numbers over time to be mapped. It suffers the disadvantage that it might not capture the full extent of these changes, since it fails to account for already commuting workers who change their commute distance.

The statistical districts have different physical sizes, contain different numbers of people, and do not necessarily equate to areas of common work-related interest. Nevertheless, the geographical positioning of the districts is fixed and remains static over the entire period of analysis, providing a consistent spatial basis for the analysis.

In analysing year-by-year statewide changes in commuter numbers we can use either in-commuter numbers I or out-commuter numbers U. The results will be very similar, because most workers who commute out of a district in NRW also commute into a district in NRW, with only 1.6% commuting into or out of the state. For our analysis of year-by-year changes in commuter numbers we use in-commuter numbers I, but this choice is entirely arbitrary. However, for analyzing issues to do with the job-housing balance the in-commuter-out-commuter differences become an essential part of the analysis, and both are used along with corresponding jobs numbers J and worker numbers W.

3. Commuter patterns in NRW and other selected states, 1994-2013

In 1994 there were 5,886,813 filled regular jobs J in NRW and by 2013 this had risen by 3.76%, to 6,108,033. Meanwhile the numbers of regular workers W living in NRW increased from 5,807,812 by 3.75%, to 6,025,661. However, the number of in-commuters I increased by the much larger percentage of 32.58%, from 2,570,873 to 3,408,366 in 2014, while the number of out-commuters U increased by 33.47%, from 2,491,872 to 3,325,994. These figures were obtained by summing the in- and out-commuter statistics for each individual district. Therefore the proportionate increase in commuting far exceeded the proportionate increase in job numbers. The increase was also greater in absolute numbers. Increases in jobs and workers of 221,220 and 217,849 were accompanied by increases of in-commuters and out-commuters of 837,493 and 834,122 respectively.

A further statistic is obtained by subtracting out-commuters U from filled jobs J in each district. This gives ‘local workers’ K, the number of people who both live and work in the same district. These numbers fell by 18.59% over the 20 year period, from 3,315,940 to 2,699,667. Appendix 1 lists these figures for all 20 years.

The patterns of the year-by-year changes in work and commuting numbers are also informative. Figure 2 displays these for jobs J, in-commuters I and local workers K, indexed to 1 in 1994.

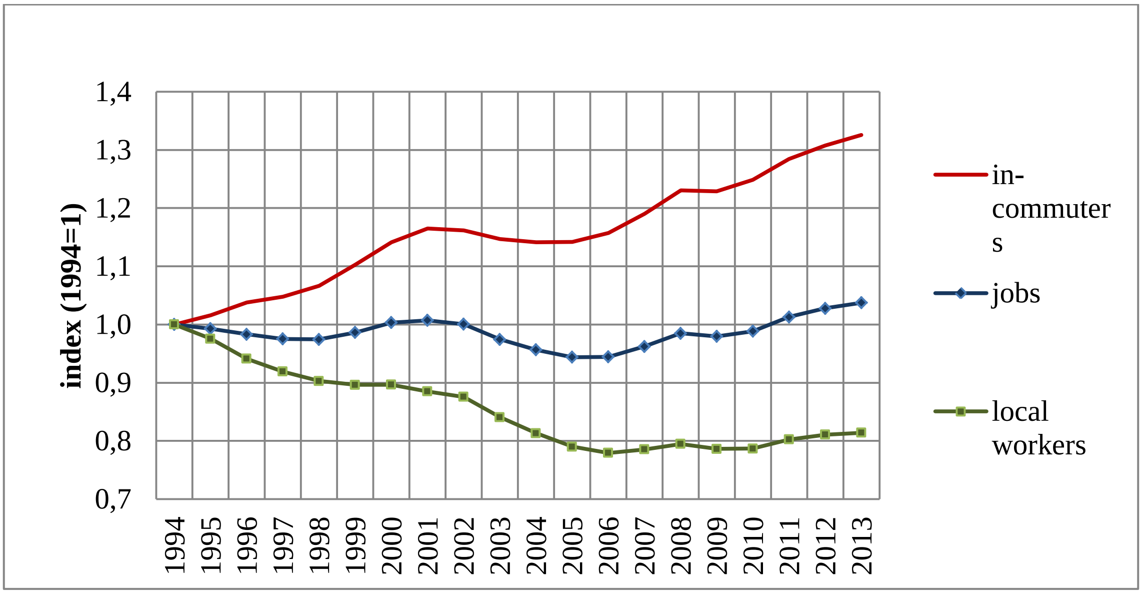

Figure 2: NRW in-commuters, jobs & local workers 1994-2013 (index =1 for 1994)

Figure 2 indicates that the patterns of change in job numbers are paralleled closely by those of in-commuters and local workers, but in-commuter numbers have an overall rising tendency and local workers a falling tendency. It appears that two phenomena are occurring simultaneously: a long-term 'signal' of increasing commuting and reducing local working, together with 'noise' consisting of short-term fluctuations which run parallel to job numbers. As with economic data displayed in Figure 1, these fluctuations correspond to the economic cycle.

To separate the long-term signal from the noise, an exponential least squares regression was performed on each of the three indexed parameters. The regression curve represents the signal, while the deviations from this curve are then considered to examine the noise. The regression function for the indexed data is given by:

$$F = B^t \tag{1}$$

where t are years from the start date and B is the annual proportionate change. This gave B-values of 1.01349 for in-commuters, 1.00090 for jobs, and 0.99581 for local workers (see Figure 3). Hence the average annual increase in numbers of in-commuters was 1.349% per year, and for jobs 0.090% per year, while the average number of local workers reduced by 0.4190% per year (1 – 0.99581 = 0.00419).

Using the first two of these variables provides a *reductio ad absurdum* test of whether the annual average increase in in-commuter numbers seems reasonably to be driven by the annual average increase in job numbers. The average number of jobs and in-commuters over the 20 year period were 5,809,561 and

2,974,845 respectively. Hence for every net extra job created in this period, the net increase in in-commuters was given by[2]:

$$Net_{JI} = \frac{\ln(1.01349)}{\ln(1.00090)} \times \frac{2974845}{5809561} = 7.6 \qquad (2)$$

This shows that for every net increase of 1 job in NRW, 7.6 more workers became commuters. Hence it cannot be that the steady, long-term increase in commuting was driven by an increase in job numbers. One new job does not produce over 7 new commuters.

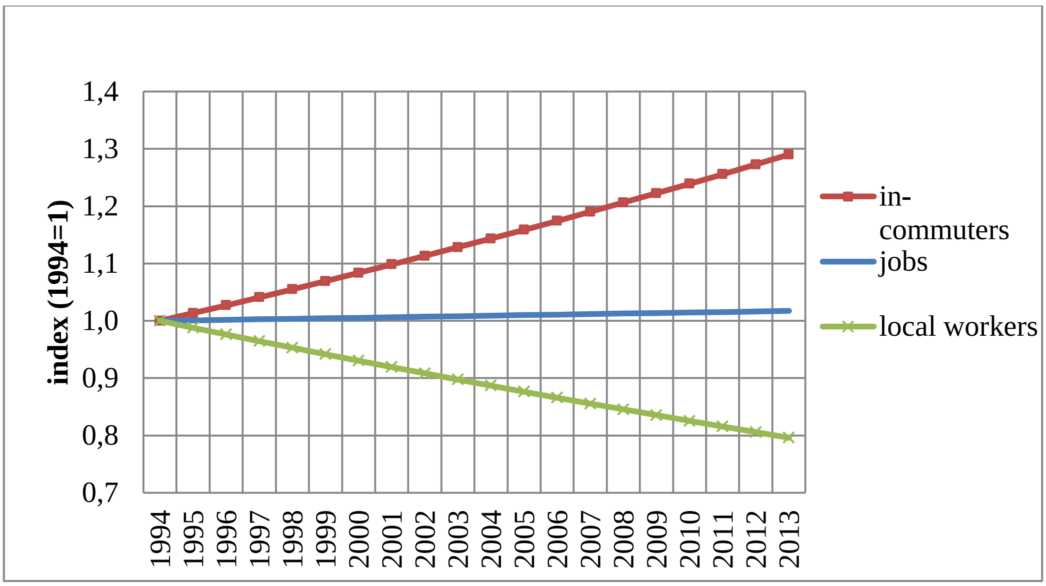

Figure 3: Exponential least squares: regressions: NRW in-commuters (B=1.01349, jobs (B=1.00090), and local workers (B=0.99581) 1994-2013

The 'noise' was examined by performing a linear least squares regression of the deviations from the jobs 'signal' against the deviations from the in-commuters signal, and then against the deviations from the local workers signal[3]. These indicated how much of the fluctuation in in-commuter numbers and local worker numbers were directly associated with the fluctuation in job numbers. Plots of these regressions are given in Figures 4 and 5.

[2] The natural log of the average proportionate annual increase is used here rather than the average proportionate increase, as the comparison is being made between two exponential curves rather than two straight lines. The log/log factor in equation (2) is effectively an elasticity: the job-numbers elasticity of in-commuter numbers.
[3] This was done using absolute rather than indexed figures, but the proportionate results would be the same for both methods.

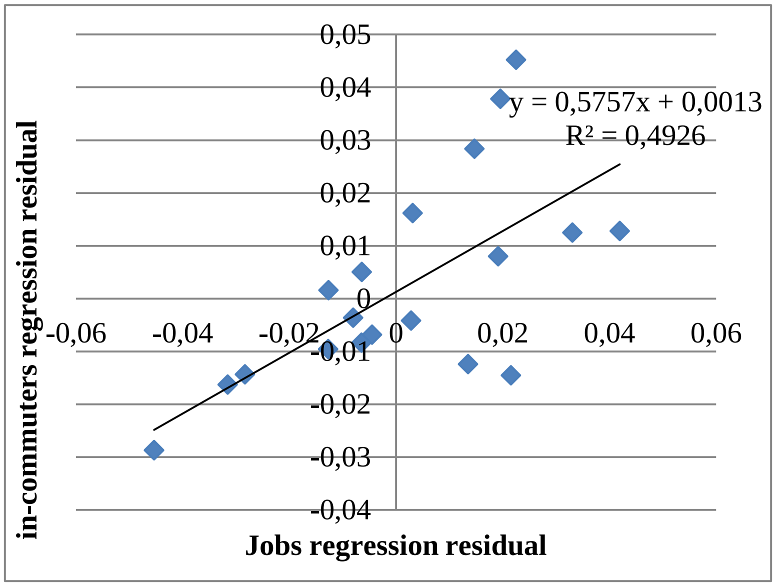

Figure 4: Residuals in NRW jobs and in-commuters exponential regressions, 1994-2013

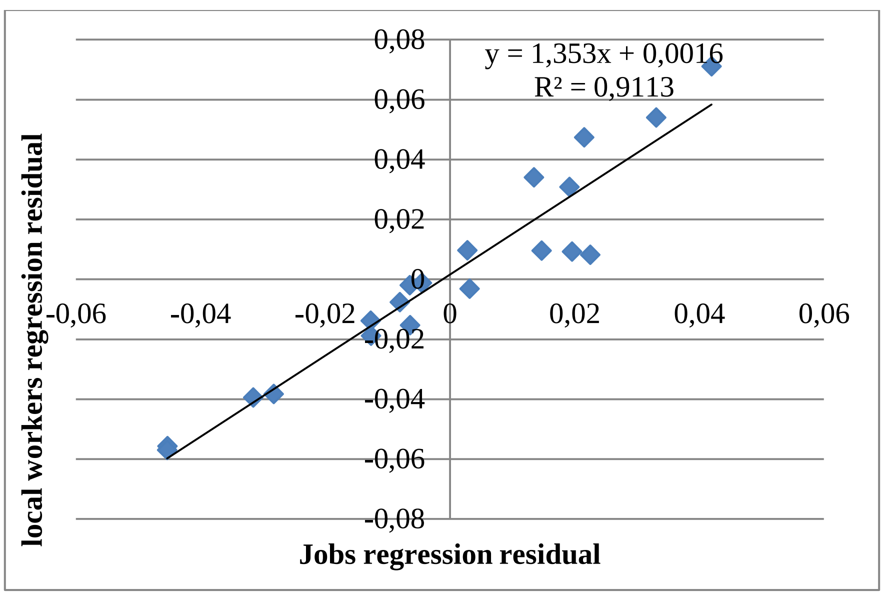

Figure 5: Residuals in NRW jobs and local workers exponential regressions, 1994-2013

The correlation coefficient R^2 of the regression equation in Figure 4 is 0.4926, indicating that slightly less than 50% of the fluctuation in in-commuter numbers is directly associated with the fluctuation in job numbers. However, the coefficient R^2 in Figure 5 is a high 0.9113, indicating that almost all the fluctuation in local worker numbers is associated with fluctuation in job numbers.

This combination of findings suggests that, while local worker employment tends to track local job availability very closely (while also steadily diminishing), commuter numbers are significantly influenced by local job numbers but not to the same extent (while also steadily rising). There seem to be other apparently random (i.e. not yet explained) stochastic effects on short term fluctuations in commuter numbers. It is also interesting that most of these stochastic effects appear in the early years of this analysis, while for 2003-2013 the correlation coefficient for in-commuters rises to 0.8751, i.e. in these years almost 90% of the fluctuations in commuter numbers are directly associated with fluctuations in job numbers.

In summary, there is a steady, persistent increase in commuter numbers and a corresponding fall in local worker numbers, and for at least the last 10 years of the analysis these have both fluctuated in synch with fluctuations in local job numbers, while in earlier years there were more unexplained fluctuations in commuter numbers.

It is informative to compare these results with those from another state with different economic characteristics. The indexed changes in numbers of jobs, in-commuters and local workers in Baden-Württemberg (see comments on this state in Sections 1 and 2) are displayed in Figure 6.

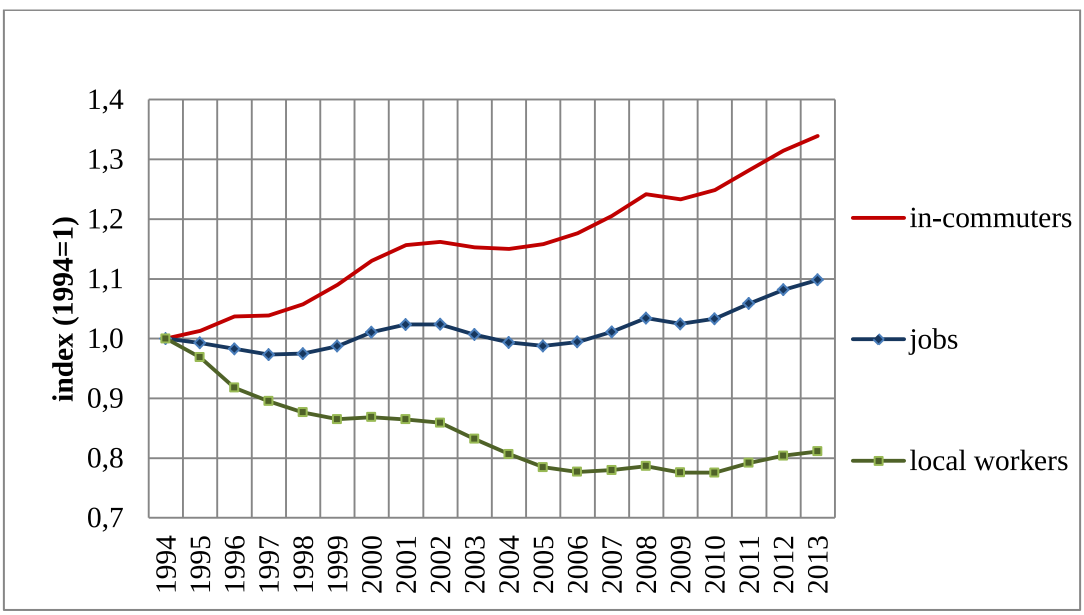

Figure 6: Baden-Württemberg in-commuters, jobs &local workers 1994-2013 (index =1 for 1994)

Visually the plots for Baden-Württemberg are similar to those for NRW. Again there is a ‘signal’ of steadily increasing commuting and reduction in local working, though for this state there is a stronger upward signal in job numbers. Meanwhile the ‘noise’ of year-by-year fluctuations in job numbers is echoed by parallel fluctuations in commuting and local working.

For Baden-Württemberg, an exponential least squared regression on the relations plotted in Figure 6 gives *B*-values of 1.01430 for in-commuters, 1.00441 for jobs, and 0.98876 for local workers, while the average number of in-commuters over the 20 year period is 2,372,681, and job numbers 3,817,063. This gives a figure of 2.0 additional commuters for every net additional job. While this is lower than for NRW, it also indicates that the increase in jobs cannot explain the increase in commuting.

Regarding the fluctuations, the R^2-value for in-commuters and jobs is 0.4033, rising to 0.7565 for 2003-2013. The R^2-value for local workers and jobs is 0.8429. This pattern is very similar to that for NRW, though for each parameter there is slightly more unexplained fluctuation.

Analyses were also performed for 1994-2013 for the states Bavaria, Rhineland-Palatinate and Saarland and for 1997-2013 for Germany as a whole (eastern states' data missing for 1994-1996). The same pattern was found for each: a long-term signal of increasing commuting regardless of long-term changes in job numbers, and a short-term year-to-year noise of job number changes paralleled by commuting changes. These results for the long-term trends are listed in Table 1.

Table 1: Average proportionate annual change in numbers of jobs, in-commuters and local workers for 5 German states in 1994-2013 and Germany 1997-2014, with additional in-commuters per additional job.

	Annual proportionate change (*B*) in numbers of:				Average number of:		Additional in-commuters per net additional job
	jobs	in-commuters	local workers	$\ln(B_I)/\ln(B_J)$	jobs	in-commuters	
Germany*	1,00290	1,00954	0,99362	3,27881	26739265	15128825	1.9
NRW	1,00090	1,01349	0,99581	14,89539	5809561	2974845	7.6
Baden-W	1,00441	1,01430	0,98876	3,22676	3817063	2372681	2.0
Bavaria	1,00662	1,01542	0,99322	2,31818	4408713	2721090	1.4
Rhineland-P	1,00130	1,01045	0,98866	8,00000	1816455	795935	3.5
Saarland	1,00170	1,00743	0,99015	4,35294	349018	237064	2.9

*Figures for Germany 1994-2009. All others 1994-2014

In every case, including Germany as a whole, the number of additional in-commuters per net additional job is greater than 1. Hence even in the extreme (and highly unlikely) case that every net additional job led to an additional commuter, there would still be a residual of additional commuters, whose commute could not be explained by increasing numbers of jobs.

Further, for NRW the figure is so high that it seems very difficult to explain fully in terms of ongoing geographical separation of workplaces and residential areas during these years. Such scenario would require that for each additional job created, at least 7 existing jobs became geographically separated from their employees (either by the employee moving house, the job location changing, or the job ending and another job starting somewhere else or with a different skills requirement). To test whether these scenarios are likely on such a large and persistent scale, a further level of analysis is required.

4. Out-commuters and 'superfluous commuting'

4.1 A 'superfluous commuters index'

A precise figure can be calculated, for every district, of the number of out-commuters who are *not forced to commute due to a mismatch between numbers of jobs and workers* in the district where they live. As there are no existing expressions in the literature we call these people 'superfluous commuters' *C*, and develop a 'superfluous commuters index' *M*.

Recalling that *J* = number of filled jobs in a district, *W* = number of employed regular workers living in that district, and *U* = number of workers who commute out of that district ('out-commuters'), the parameter *C* is given by:

$$\text{if } J \geq W \text{ then } C = U \quad (3)$$

but:

$$\text{if } J < W \text{ then } C = U - (W - J). \quad (4)$$

In prosaic terms, if there are more jobs than workers in a district (or the same number of each), all workers who commute out of the district are defined as superfluous commuters (there are enough jobs there for them if the jobs suit them). On the other hand, if there are fewer jobs than workers in a district, only *some* of the workers who commute out of the district are defined as superfluous commuters, namely the excess of the total number who out-commute, over the number who have to out-commute because of the local shortage of jobs.

The superfluous commuters index *M* is defined as the superfluous commuters as a proportion of the workers living in the district:

$$M = {}^{C}/_{W} \quad (5)$$

Values for *C* and *M* were found for each of the 396 districts in NRW and summed for the state, for each of the years 1994-2013. During this period the number of superfluous commuters *C* increased from 1,877,265 to 2,627,218. This increase, of 39.95%, exceeds the percentage increase in total out-commuter numbers, of 33.48%. The superfluous commuter index *M* for the state increased from 0.3232 to 0.4360, indicating that the percentage of workers who were superfluous commuters increased from 32.32% in 1994 to 43.60% in 2013. Figure 7 displays how this index changed over time (line with square markers), together with a best fit curve (plain line). Yearly figures are listed in Appendix 1.

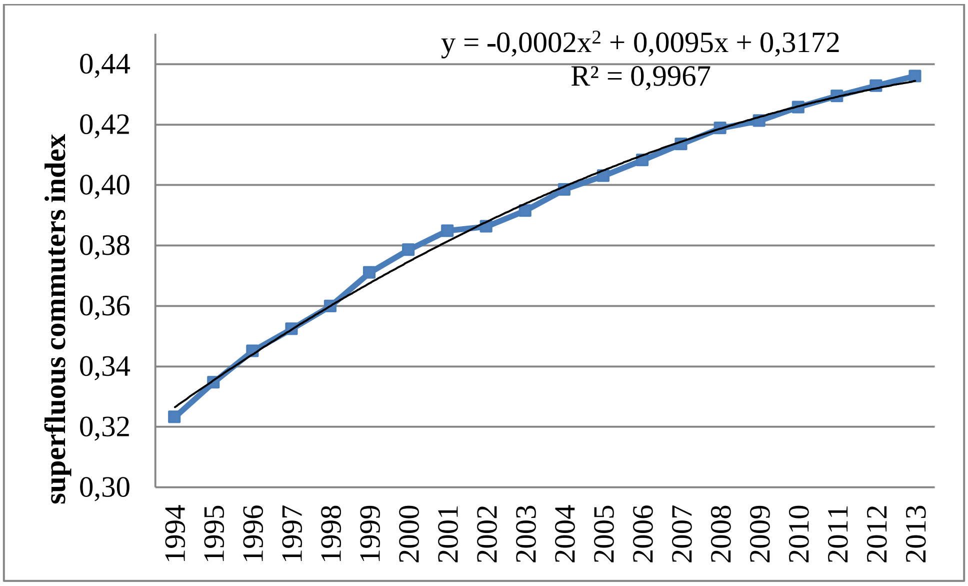

Figure 7: NRW superfluous commuters index 1994-2013, actual and modeled

The index rises continually, but the gradient of its rise reduces. A very close fit with this curve (R^2=0.9967) is obtained with the quadratic function:

$$M = -0.0002t^2 + 0.0095t + 0.3172 \quad (6)$$

where *t* are years from 1994.

Differentiating this function indicates it would reach a peak after 24 years, but there is no practical reason why it could not continue to increase beyond this. A reason for the flattening tendency is that in each district there is only a certain sized pool of resident regular workers who are not already commuting, and as more become commuters this pool diminishes proportionately.

Clearly a very large proportion of workers commute for reasons other than a simple mismatch between accommodation and jobs. For example, NRW's largest city and employer, Cologne, had 496,182 jobs in 2013 but required a net daily influx of 133,221 in-commuters due to the shortage of workers living in the city. However, it lost 106,319 workers each day to jobs elsewhere, so that 239,540 in-commuters were needed to fill the local jobs. All 106,319 of those commuting to jobs elsewhere could theoretically work in the city if jobs there suited them. It must also be noted that Cologne's *excess* of jobs over locally resident workers grew by 22,303 in 1994-2013, similar to other large NRW cities such as Düsseldorf (18,131), Essen (14,349), Münster (8,676), Ratingen (7,729) and Bonn 7,654).

A possible reason for the steady increase in superfluous commuting is the jobs-skills mismatch. Graph 1 showed a shift in NRW's economy from production toward service industry. This amounts to about 1.86% per year in terms of value added. This would suggest an average annual change in the types of jobs available of somewhere in the vicinity of that figure. A significant portion of new, service-oriented jobs would be in different locations from older, production-oriented jobs. In order to match their skills to the new jobs, some workers would become commuters, some would change their commute, and others would cease commuting. On balance commuting would be expected to increase, if the assumption is correct that in the past workers tended to live close to their jobs. This lends support to the jobs-homes-skills hypothesis.

The superfluous commuter index *M* for the state of Baden-Württemberg is similar to that for NRW both in magnitude and curvature over time. This is displayed in Figure 8, together with a quadratic curve of best fit.

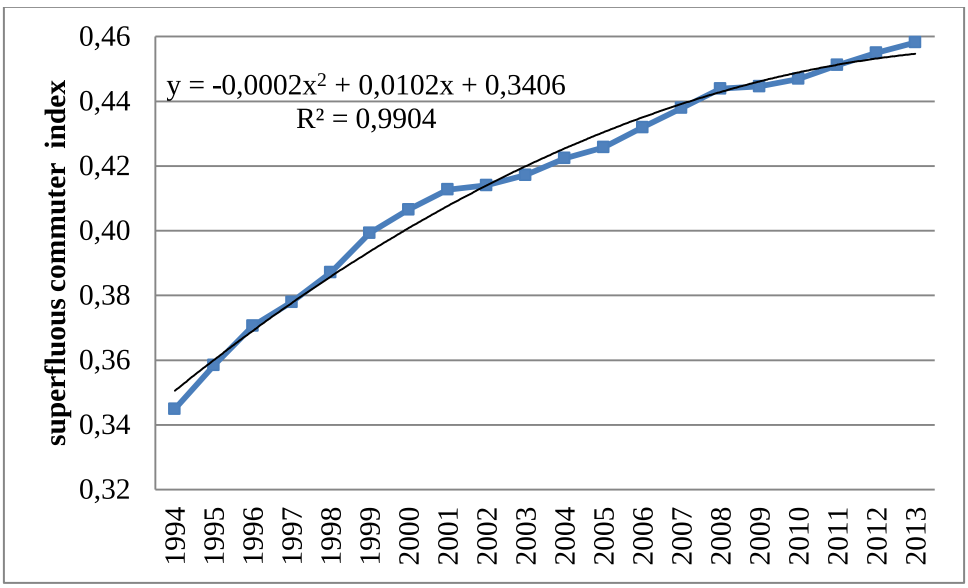

Figure 8: Baden-Württemberg superfluous commuter index 1994-2013, actual and modeled

The modeling equation for the Baden-Württemberg case is given by:

$$M = -0.0002t^2 + 0.0102t + 0.3406 \quad (7)$$

The curvature (coefficient of t^2) is the same for each of the two states. The underlying gradient is 7.4% higher for Baden-Württemberg, at 0.0102 compared to 0.0095 for NRW. The underlying magnitude, given by the constant term, is 6.9% higher for Baden-Württemberg. The districts in Baden-Württemberg are geographically smaller than those in NRW, at 32.47 km^2 compared to 86.11km^2, giving an average distance from the centre to the boundary of 3.21 km and 5.25 km respectively. Hence job changes resulting in small increases in work travel distance are captured more fully in Baden-Württemberg's data than in NRW's, so it is not possible to draw conclusions from these differences. Similar analyses performed on all 11 western German states showed the same pattern of steadily increasing superfluous commuting.

4.2 Changes in superfluous commuting

A further level of analysis was performed by examining how the *change* in the superfluous commuter index between 1994 and 2013 for each district in NRW varied in relation to the proportionate gain in jobs over that period for that district (in order to see how changes in superfluous commuting related to job availability). A scatterplot of this relation, covering all 396 districts, is given in Figure 9. The relation is clearly positive (gradient β=0.1737), giving the counter-intuitive result that the higher the proportionate job number increase in a district, the bigger the increase in the proportion of workers who commute *out* of it (superfluously) for work.

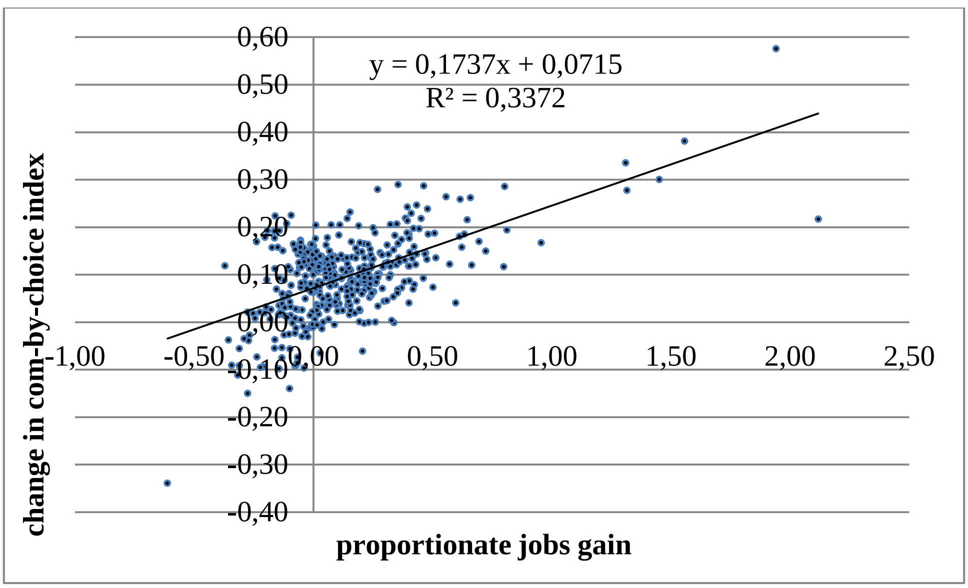

Figure 9: NRW change in superfluous commuter index with proportionate jobs gain, all districts 1994-2013

However, the reverse is the case for the cities with the most jobs. Figure 10 gives a plot for just the 11 cities with more than 100,000 jobs, representing 37% of all jobs in NRW. Here the trend is clearly negative (gradient β=-0.1657), with a reasonably high pseudo-correlation coefficient R^2 = 0.6580. Further, this trend is evident regardless of whether these cities have gained or lost jobs. For every 1% proportionate jobs gain, the proportionate *increase* in numbers of superfluous commuters (but not the absolute number) reduces by 0.1657%. When there are more jobs in the district, the *rate increase* of *loss* of workers to jobs outside the district slows (but the *losses* are not reduced); when there are fewer jobs, the rate of increase of loss increases. This lends some support to the jobs-homes-skills hypothesis.

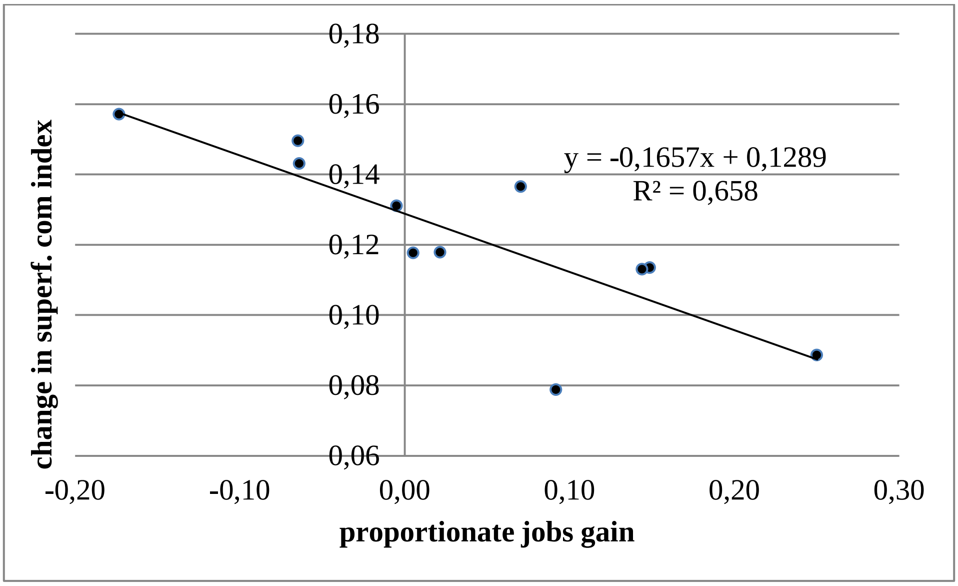

Figure 10: NRW change in superfluous commuters index with proportionate jobs gain, 11 most job-rich districts 1994-2013

However, it does not fully explain the overall out-commuting trend, as superfluous commuter indices are high and increasing even in job-rich districts. Note that the vertical axis is the *change* in superfluous commuter index, and is always positive. The daily exit of workers continues to increase from centres which are becoming more job-rich.

When the 55 job-richest districts are considered – those with 20,000 jobs or more, which together supply 65% of the jobs in NRW – the slope of the gradient is still negative but less steep (β=-0.1199) and the pseudo-correlation coefficient lower (R^2=0.2093). This is displayed in Figure 11. It would appear that in NRW's medium to large population centres, despite the underlying trend of ever-increasing superfluous commuting, there is a countervailing trend of finding jobs close to home when these become available, and commuting out when jobs are in short supply.

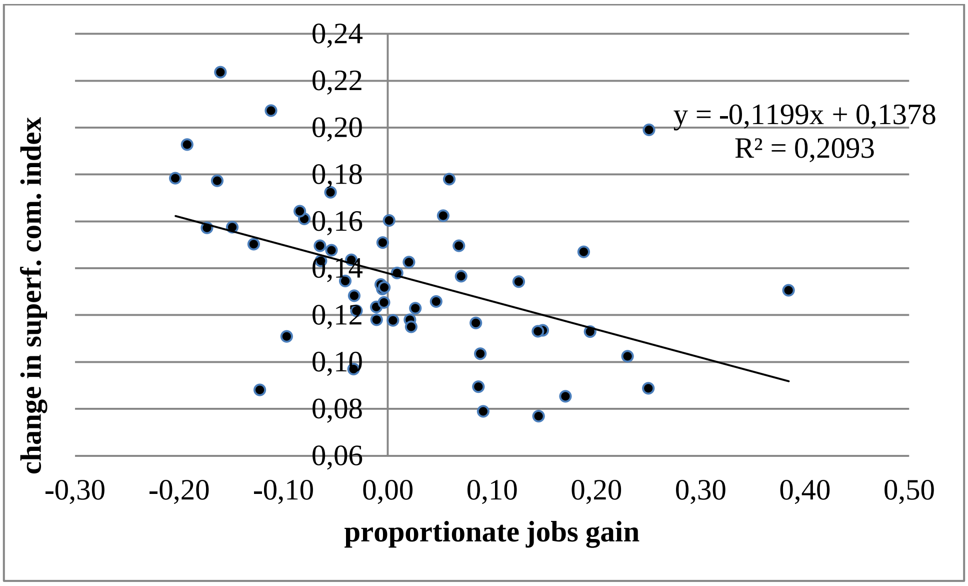

Figure 11: NRW change in superfluous commuters index with proportionate jobs gain, 55 most job-rich districts 1994-2013

In districts with smaller population and fewer jobs the gradient turns from negative to positive. Figure 12 displays the plot for NRW's 202 least job-rich districts, which each have less than 2,000 jobs and together supply just 1% of jobs in NRW. The gradient β=0.2115 indicates that as the proportionate number of jobs increases, the rate of (superfluous) out-commuting increases (R^2 = 0.5068). There is an increasing tendency to work close to home when local jobs become scarcer, and commute out when they become more numerous. It is difficult to see why this should be so. One possible explanation might be that for small centres, an increase in job offers in one's home district is paralleled by increasing job offers in the surrounding districts, giving workers a wider field of choice. Alternatively, it could be that workers who already have jobs elsewhere are shifting house to these districts, causing the local economy to improve.

However, as these districts only make up 1% of the jobs, their commuting patterns play only a very small role in NRW overall.

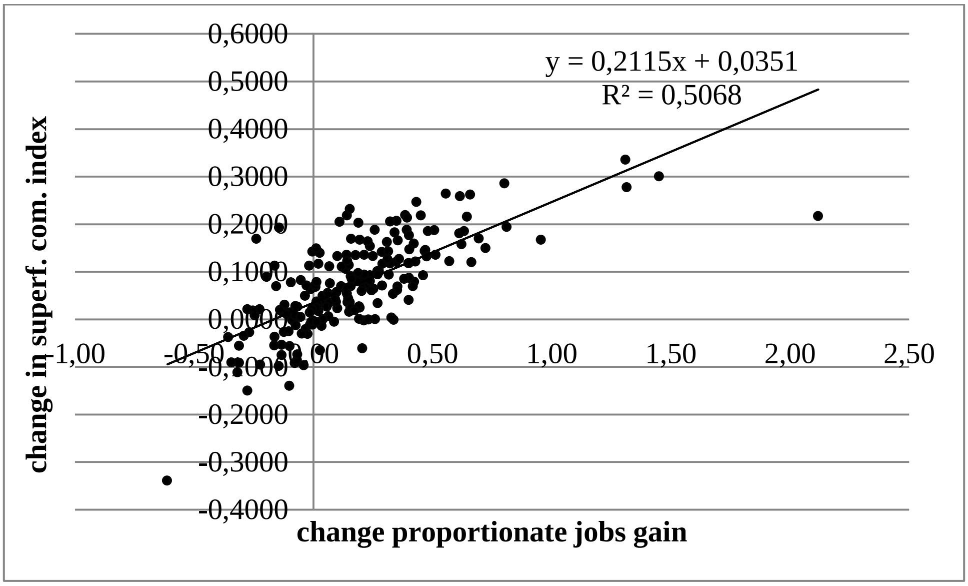

Figure 12: NRW change in superfluous commuter index with proportionate jobs gain, 202 least job-rich districts

It was not possible to perform a complete analysis of this type for Baden-Württemberg over 1994-2013, as changes were made to a number of district configurations in 2010. However, it was possible to select out the 15 job-richest districts, where there have been no configuration changes, which supply 37.5% of Baden-Württemberg's jobs. A plot of change in superfluous commuting against proportionate change in job numbers is given in Figure 13.

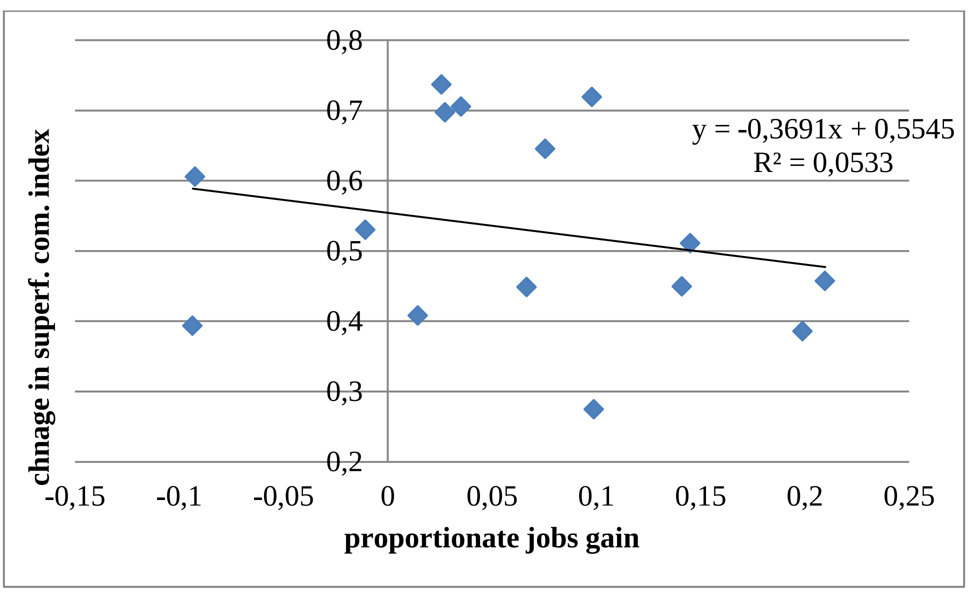

Figure 13: Baden-Württemberg change in superfluous commuter index with proportionate jobs gain, 15 most job-rich districts

The relation for these job-rich centres in Baden-Württemberg is similar to that for similar centres in NRW, though there is more scattering of data points, with a very low R^2 value of 0.0533. The slope is steeper, at β = -0.3691. This could indicate that superfluous commuting in big job centres in Baden-Württemberg is more sensitive to local job availability than in NRW, but because of the low R^2 value this cannot be asserted with confidence. It does appear, however, that a similar situation pertains in big job centres in both states: there is an underlying (and unexplained) increase in superfluous commuting, together with an intuitively expected effect of a lower increase in superfluous commuting when more local jobs are available.

5. Discussion

This analysis has brought to light three main phenomena regarding commuting in NRW, which have parallels in Baden-Württemberg and to some extent other states and Germany as a whole. Firstly, there has been a continuous increase in numbers of commuters and a reduction in local working, alongside year-by-year fluctuations in both of these which run roughly parallel to fluctuations in the total number of jobs. This is the case for NRW, Baden-Württemberg, Germany as a whole, and three other states on which a partial analysis was performed: Bavaria, Rhineland-Palatinate and Saarland. This two-pronged trend can be described as signal and noise. The signal is the relentless upward trend in commuting, with commuter numbers increasing in NRW by an average of 1.35% per year in 1994-2013. It is unreasonable to suggest long-term commuter numbers are driven by long-term job numbers in NRW, as this would imply that each net additional job causes about 7 non-commuting workers to become commuters.

The noise, which corresponds with the economic cycle, indicates that year-by-year fluctuations in job numbers do influence commuter numbers, almost one-to-one in the last decade, alongside the steady upward trend. This is not surprising. When job numbers fall (and rise), both commuters and non-commuters lose (and gain) jobs.

Secondly, the increase in commuting is not caused by a simple geographical mismatch between job and residence locations – the jobs-homes hypothesis. This is evident because there has been a steadily increasing ‘superfluous commuting’ trend. Far more workers commute out of job-rich districts than the number who need to for reasons of jobs-housing mismatches. This trend is very similar in NRW and Baden-Württemberg. In NRW, in job-rich cities such as Cologne, Düsseldorf, Essen, Dortmund and Bonn, there are more than enough jobs for every potential worker who lives there, but hundreds of thousands of workers commute out of these cities to jobs elsewhere, while others commute inwards to fill the jobs which would otherwise be left vacant. The situation is similar in Baden-Württemberg’s biggest job centres such as Stuttgart, Mannhein, Karlsruhe, Freiburg, Ulm, Heidelberg and Heilbronn. In NRW in 1994, 43% of workers commuted out of their district, and over three-quarters of these, or 32% of all workers, were ‘superfluous commuters’: they were not forced to commute through jobs-housing mismatches. These figures have been steadily rising. By 2013, 55% of workers were commuting out of their district, and 80% of these, or 44% of all workers, were superfluous commuters. The sheer magnitude of this phenomenon also makes it difficult to explain in terms of skills mismatches between workers and local jobs – the jobs-homes-skills hypothesis. Further, a large proportion of these workers simply commute from one large, job-rich centre to another, such as along the high-speed road and rail corridor between Cologne and Düsseldorf. These two cities exchanged a total of 20,222 workers per day in 2013 (IT-NRW, 2013).

Thirdly, there is a countervailing tendency to the above: there is strong evidence that in the job-rich districts which supply the majority of jobs in NRW, there is a tendency for the increase in the proportion of superfluous commuters to diminish when there are proportionate increases in the number of jobs, and to rise when the proportionate number of jobs falls. More jobs in a big city leads to a reduction in the upward trend of people commuting out (though not to a halt or reversal of the trend). This most likely means that as job numbers increase, there is a higher probability that the skills of specific local workers will find local job matches. This offers support to the jobs-homes-skills hypothesis. However, this hypothesis does not seem to explain the underlying magnitude of the superfluous commuter index, nor its persistent upward trend.

This suggests there are other determinants of commuting which are not to do with jobs-homes-skills mismatches. In this respect the city network theory (Reggiani et al., 2011) becomes attractive. It suggests much commuting happens because it is necessary and inherently rewarding for both commuters and employers, an essential part of the networking of skilled workers that facilitates the information flows that fuel a knowledge-rich economy.

This also raises questions about the rebound effect. An inherent feature of a knowledge-rich economy is energy efficiency. Increasing energy efficiency is also a strong policy plank of the NRW state government (EA-NRW, 2014). If the city-network hypothesis is correct, an unintended consequence of this efficiency gain is that more energy is consumed in commuting. This would be an example of the ‘indirect’ rebound effect (Sorrell and Dimitropoulos, 2008), as an energy efficiency increase in one sector spills over into an increase in the consumption of energy services in another sector.

A back-of-an-envelope calculation of this indirect rebound effect could be made as follows. In the period 1994-2011 the energy efficiency of NRW’s economy, measured as real output per unit of energy consumption, increased by an average annual rate of 0.783% based on an exponential least squares regression of actual values for those years (BMWi, 2014. Data for 2012-13 not available). Coinciding with these years, the average annual increase in commuter numbers was 1.309%.

Hence the economic energy efficiency elasticity of commuting numbers in NRW is given by:

$$\eta_{fC} = \frac{\ln(1.01309)}{\ln(1.00783)} = 1.667, or\ 166.7\% \tag{8}$$

This suggests an indirect rebound effect of around 167%, meaning that every 1% increase in statewide energy efficiency is associated with a 1.67% increase in commuter numbers. This seems a reasonable result given the magnitude and consistency of commuting. The comparable elasticity figures for other states are: Baden-Wüttemberg 0.9020; Baravia 0.7892; Schlieswig-Holstein 0.4426; Rheinland-Palatinate 0.7717 and Germany as a whole 1.1494. NRW clearly stands out within Germany as having an above-average indirect commuter rebound effect as measured in these terms.

This can also be seen in terms of approximate energy consumption and CO_2 emission increases from commuting. In NRW there were 834,122 more commuters in 2013 than in 1994. If the average commute in NRW is 19 km twice per day (IT-NRW, 2013), 250 days per year, this represents an increase of approximately 7.9 billion km of travel per year, which would increase CO_2 emissions by a very approximate estimate of 1 million tonnes per year.

6. Conclusions and recommendations for further study

This analysis used precise Federal data on job and worker locations in the 396 statistical districts of North-Rhine Westphalia (NRW) in each of the years 1994-2013 to explore changes in commuting patterns. To some extent it also analysed corresponding data from Germany's 13,271 statistical districts, with emphasis on the state of Baden-Württemberg and to some extent Bavaria, Rhineland-Palatinate and Saarland, while the commuting profiles of all other German states were analysed less intensely to provide overall comparison. Defining a 'commuter' as a worker who crosses at least one statistical boundary in traveling to work, it calculated precise measures for increases in commuter numbers in NRW, and compared these with other states, plus Germany as a whole.

Commuting in NRW increased steadily at an average rate of 1.35% per year, with over 3.3 million commuters in 2013 compared to 2.5 million in 1994. Fluctuations in this increase correspond with fluctuations in job numbers, but the overall, steady increase in commuting cannot be explained by job number increases, as this would imply there are 7 additional commuters for every net additional job. Further, far more workers commute than need to for reasons of jobs-homes mismatch. The percentage of workers commuting away from numerically available jobs in their local district – called here 'superfluous commuting' – rose from 32.23% in 1994 to 43.60% in 2013. Some commuting seems to be determined by jobs-homes-skills mismatches, as the increase in the rate of superfluous commuting is less in cities with strong job growth, and more where job growth is negative. This cannot fully explain the growth in commuting, however, as the increase in the rate of superfluous out-commuting continues even in large cities with a growing surfeit of jobs. A similar though more limited analysis for Baden-Württemberg, and more limited analyses for other states and Germany as a whole, suggested that these findings may be applicable much more widely in Germany.

A significant proportion of commuting numbers and increase may need to be explained by a hypothesis such as the city network concept (Reggiani et al., 2011). This posits that commuting serves the purpose of networking essential knowledge over geographical areas which are bound together in knowledge and information-rich economic activity, and that people thereby choose to commute because of its inherent advantages.

More research is needed to test these findings further. To begin with, there is scope for investigation of the reasons why workers commute. Semi-structured interviews (Flyvberg, 2004) with a limited number of workers who commute would enable researchers to hear these people's own reasons for commuting, some of which may not have yet been considered in academic studies. Based on findings from such interviews, a quantitative questionnaire could be distributed more widely, to find out how much of each of the reasons given by interviewees in the qualitative investigation are prevalent in the determinants of commuting. Such an investigation could also be extended to employers, to find out what sort of preferences they have for commuters, if any, and why.

Secondly, the quantitative side of this study would be enhanced by a more in-depth study of a smaller region using statistics on the destinations of out-commuters and the origins of in-commuters. These statistics are available from the German Labour Agency (see above), but are cumbersome to use exhaustively since commuters come and go from and to so many places.

Thirdly, the investigation would be enhanced by studies on modal split among commuters. The Labour Agency's statistics do not include this information, and to date only small, local studies are available.

Finally, since commuting consumes increasing quantities of energy in an age when energy efficiency is strongly promoted, there is a need for more in-depth study on commuting and the rebound effect. If the city network is a main determinant of commuting, there are strong indirect rebound effects: energy efficiency increases in the wider economy are making city networks more viable, which is leading to more commuting and more energy consumption. A back-of-the-envelope calculation put the economy-wide energy efficiency elasticity of commuter numbers – a relevant measure of the indirect rebound effect – at around 167%. It would be useful to explore this issue in more detail.

Acknowledgements

The authors would like to acknowledge research funding received by the Ministry of Science and Research (MIWF) of the State of North-Rhine Westphalia (NRW), Germany, for studying rebound effects in NRW, and management of the grant by the Projektträger Energie, Technologie und Nachhaltigkeit (ETN) (Grant No. 313-005-2013-W029-MIWF).

References

Adair A, McGreal S, Smyth A, Cooper J, Ryley T (2000) House Prices and Accessibility: The Testing of Relationships within the Belfast Urban Area. Housing Studies 15: 699-716.

Axisa J, Scott M, Newbold K (2012) Factors influencing commute distance: a case study of Toronto's commuter shed. Journal of Transport Geography 24: 123–129.

Berkhout, Peter H.G., Muskens, Jos. C., Velthuijsen, Jan W., 2000. Defining the rebound effect. Energy Policy 28 (6/7), 425–432.

BMWi (Bundesministerium für Wirtschaft und Energie) (2014) Zahlen und Fakten: Energiedaten: Nationale und Internationale Entwicklung. Berlin: BMWi.

Boussauw K, Witlox F (2009) Introducing a commute-energy performance index for Flanders. Transportation Research Part A 43: 580–591.

Brueckner J (2000) Urban sprawl: diagnosis and remedies. International Regional Science review, 23: 160-171.

Buchanan N, Barnett R, Kingham S, Johnston D (2006) The effect of urban growth on commuting patterns in Christchurch, New Zealand. Journal of Transport Geography 14: 342–354.

Cassel S, Macuchova Z, Rudholm N, Rydell A (2013) Willingness to commute long distance among job seekers in Dalarna, Sweden. Journal of Transport Geography 28: 49–55.

Crane R, Takahashi L (2009) Sex changes everything: the recent narrowing and widening of travel differences by gender. Public Works Management and Policy 13: 328–337.

Destatis (Statistisches Bundesamt Deutschland) (2014a) Auf einen Blick: Bevölkerung im Dezember 2012 auf Grundlage des Zensus 2011. Web resource: https://www.destatis.de/DE/ZahlenFakten/LaenderRegionen/Regionales/Gemeindeverzeichnis/Administrativ/AdministrativeUebersicht.html accessed 03 July, 2014.

Drews J, Frohn M (2011) Pendleratlas Region Aachen: Analyse der Pendlerströme und deren wirtschaftliche Relevanz im Kammerbezirk Aachen. Aachen, Germany: Industrie- und Handelskammer Aachen.

EA (Energie-Agentur)-NRW (2014) Über uns. Web resource of the NRW government: http://www.energieagentur.nrw.de/themen/ueber-uns-5272.asp accessed 08 July, 2014.

Eurostat (2009) Energy, Transport and Environment Indicators: 2009 edition. European Communities, Luxembourg.

Flyvberg B (2004) Five misunderstandings about case-study research, in: C. Seale, G. Gabo, J.F. Gubrium, D. Silverman (Eds.), Qualitative Research Practice, Sage, London/Thousand Oaks, CA, pp. 420–434.

Frondel M, Ritter N, Vance C (2012) Heterogeneity in the rebound effect: Further evidence for Germany. Energy Economics 34: 461–467.

García-Palomares J (2010) Urban sprawl and travel to work: the case of the metropolitan area of Madrid. Journal of Transport Geography 18: 197–213.

Green A, Hogarth T, Shackleton R (1999) Longer distance commuting as a substitute for migration in Britain: a review of trends, issues and implications. International Journal of Population Geography 5: 49–67.

IT-NRW (2012) Statistisches Jahrbuch Nordrhein-Westfalen 2012. Düsseldorf: Information und Technik Nordrhein-Westfalen.

IT-NRW (2013) Berufspendler NRW (Excel table). Available at http://www.it.nrw.de/ accessed 13 May, 2014.

Khazzoom, J. Daniel, 1980. Economic implications of mandated efficiency in standards or household appliances. Energy Journal 1 (4), 21– 40.

McQuaid R, Greig M, Adams J (2001) Unemployed job seekers attitudes towards potential travel-to-works times. Growth and Change 32(3): 355–368.

McQuaid R, Chen T (2012) Commuting times - The role of gender, children and part-time work. Research in Transportation Economics 34: 66-73.

Maggi C (2000) Key factors of structural change in North Rhine-Westphalia. INEF Report: Gerhard-Mercator-Universität, Gesamthochschule Duisburg.

Marqiue A, Reiter S (2012) A method for evaluating transport energy consumption in suburban areas. Environmental Impact Assessment Review 33: 1–6.

Modarres A (2013) Commuting and energy consumption: toward an equitable transportation policy. Journal of Transport Geography 33: 240–249.

MOP (German Mobility Panel) (2011) http://www.ifv.uni-karlsruhe.de/MOP.html

NRW (2012) Energie-Daten NRW 2012. Ministerium für Klimaschutz, Umwelt, Landwirtschaft, Natur- und Verbraucherschutz des Landes Nordrhein-Westfalen.

Reggiani A, Bucci B, Russo G, Haas A, Nijkamp P (2011) Regional labour markets and job accessibility in City Network systems in Germany. Journal of Transport Geography 19: 528–536.

Sorrell S, Dimitropoulos J (2008) The rebound effect: Microeconomic definitions, limitations and extensions. Ecological Economics 65: 636 – 649.

Statistika (2014a) Anzahl der Beamten und Richter in Deutschland zum 30. Juni 2013 nach Beschäftigungsbereichen**.** Web resource: http://de.statista.com/statistik/daten/studie/37096/umfrage/beamte-und-richter-in-deutschland/ accessed 03 July, 2014.

Thomas T, Tutert S (2013) An empirical model for trip distribution of commuters in The Netherlands: transferability in time and space reconsidered. Journal of Transport Geography 26: 158–165.

Travisi C, Camagni R, Nijkamp P (2010) Journal of Transport Geography 18: 382–392.

Verhetsel A, Vanelslander T (2010) What location policy can bring to sustainable commuting: an empirical study in Brussels and Flanders, Belgium. Journal of Transport Geography 18: 691–701.

Winkelmann U (2008) Berufspendler in Baden-Württemberg – keine (ganz) unbekannten Wesen. Statistisches Monatsheft Baden-Württemberg 3/2008.

Zhao P, Lu B, de Roo G (2011) Impact of the job-housing balance on urban commuting in Beijing in the transformation era. Journal of Transport Geography 19: 59–69.

Appendix 1. Summary of principal statistics for NRW commuting

	Workers B (Wohnort)	Jobs J (Arbeitsort)	In-commuters I (Einpendler)	Out-commuters U (Auspendler)	local workers K	superfluous commuters C	superfluous commuter index M
1994	5807812	5886813	2570873	2491872	3315940	1877265	0,3232
1995	5766077	5845738	2611146	2531485	3234592	1930253	0,3348
1996	5705871	5789336	2668555	2585090	3120781	1969008	0,3451
1997	5650414	5741031	2693163	2602546	3047868	1990972	0,3524
1998	5643626	5736900	2742438	2649164	2994462	2031472	0,3600
1999	5706188	5806864	2834686	2734010	2972178	2117092	0,3710
2000	5798624	5907280	2934168	2825512	2973112	2194954	0,3785
2001	5807555	5929580	2994964	2872939	2934616	2234996	0,3848
2002	5777775	5889812	2986323	2874286	2903489	2231707	0,3863
2003	5628040	5736058	2947768	2839750	2788290	2203559	0,3915
2004	5531200	5631485	2934276	2833991	2697209	2204187	0,3985
2005	5460175	5556270	2936335	2840240	2619935	2200645	0,4030
2006	5466893	5560958	2976020	2881955	2584938	2231563	0,4082
2007	5575603	5665640	3060759	2970722	2604881	2305897	0,4136
2008	5702469	5798424	3163069	3067114	2635355	2388214	0,4188
2009	5675245	5766861	3159114	3067498	2607747	2390567	0,4212
2010	5732053	5820035	3210540	3122558	2609495	2440424	0,4258
2011	5876380	5963603	3302421	3215198	2661182	2523538	0,4294
2012	5968823	6050508	3361915	3280230	2688593	2583737	0,4329
2013	6025661	6108033	3408366	3325994	2699667	2627218	0,4360

E.ON Energy Research Center

fcn Institute for Future Energy Consumer Needs and Behavior

RWTH AACHEN UNIVERSITY

List of FCN Working Papers

2014

Sunak Y., Madlener R. (2014). Local Impacts of Wind Farms on Property Values: A Spatial Difference-in-Differences Analysis, FCN Working Paper No. 1/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Garnier E., Madlener R. (2014). Leveraging Flexible Loads and Options-based Trading Strategies to Optimize Intraday Effects on the Market Value of Renewable Energy, FCN Working Paper No. 2/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Kerres B., Fischer K., Madlener R. (2014). Economic Evaluation of Maintenance Strategies for Wind Turbines: A Stochastic Analysis, FCN Working Paper No. 3/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Loucao S., Madlener R. (2014). External Effects of Hydraulic Fracturing: Risks and Welfare Considerations for Water Supply in Germany, FCN Working Paper No. 4/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Popov M., Madlener R. (2014). Backtesting and Evaluation of Different Trading Schemes for the Portfolio Management of Natural Gas, FCN Working Paper No. 5/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Madlener R., Reismann T. (2014). The Great Pacific Garbage Patch: A Preliminary Economic Analysis of the 'Sixth Continent', FCN Working Paper No. 6/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Blum J., Madlener R., Michelsen C.C. (2014). Exploring the Diffusion of Innovative Residential Heating Systems in Germany: An Agent-Based Modeling Approach, FCN Working Paper No. 7/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Tejada R., Madlener R. (2014). Optimal Renewal and Electrification Strategy for Commercial Car Fleets in Germany, FCN Working Paper No. 8/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Galvin R., Madlener R. (2014). Determinants of Commuter Trends and Implications for Indirect Rebound Effects: A Case Study of Germany's Largest Federal State of NRW, 1994-2013, FCN Working Paper No. 9/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

2013

Grieser B., Madlener R., Sunak Y. (2013). Economics of Small Wind Power Plants in Urban Settings: An Empirical Investigation for Germany, FCN Working Paper No. 1/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, January.

Madlener R., Specht J.M. (2013). An Exploratory Economic Analysis of Underground Pumped-Storage Hydro Power Plants in Abandoned Coal Mines, FCN Working Paper No. 2/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Kroniger D., Madlener R. (2013). Hydrogen Storage for Wind Parks: A Real Options Evaluation for an Optimal Investment in More Flexibility, FCN Working Paper No. 3/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Petersen C., Madlener R. (2013). The Impact of Distributed Generation from Renewables on the Valuation and Marketing of Coal-Fired and IGCC Power Plants, FCN Working Paper No. 4/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Oberst C.A., Oelgemöller J. (2013). Economic Growth and Regional Labor Market Development in German Regions: Okun's Law in a Spatial Context, FCN Working Paper No. 5/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Harmsen - van Hout M.J.W., Ghosh G.S., Madlener R. (2013). An Evaluation of Attribute Anchoring Bias in a Choice Experimental Setting. FCN Working Paper No. 6/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Harmsen - van Hout M.J.W., Ghosh G.S., Madlener R. (2013). The Impact of Green Framing on Consumers' Valuations of Energy-Saving Measures. FCN Working Paper No. 7/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Rosen C., Madlener R. (2013). An Experimental Analysis of Single vs. Multiple Bids in Auctions of Divisible Goods, FCN Working Paper No. 8/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April (revised November 2013).

Palmer J., Sorda G., Madlener R. (2013). Modeling the Diffusion of Residential Photovoltaic Systems in Italy: An Agent-based Simulation, FCN Working Paper No. 9/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Bruns S.B., Gross C. (2013). What if Energy Time Series are not Independent? Implications for Energy-GDP Causality Analysis, FCN Working Paper No. 10/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, June.

Bruns S.B., Gross C., Stern D.I. (2013). Is There Really Granger Causality Between Energy Use and Output?, FCN Working Paper No. 11/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Rohlfs W., Madlener R. (2013). Optimal Power Generation Investment: Impact of Technology Choices and Existing Portfolios for Deploying Low-Carbon Coal Technologies, FCN Working Paper No. 12/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Rohlfs W., Madlener R. (2013). Challenges in the Evaluation of Ultra-Long-Lived Projects: Risk Premia for Projects with Eternal Returns or Costs, FCN Working Paper No. 13/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Michelsen C.C., Madlener R. (2013). Switching from Fossil Fuel to Renewables in Residential Heating Systems: An Empirical Study of Homeowners' Decisions in Germany, FCN Working Paper No. 14/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Rosen C., Madlener R. (2013). The Role of Information Feedback in Local Reserve Energy Auction Markets, FCN Working Paper No. 15/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Himpler S., Madlener R. (2013). A Dynamic Model for Long-Term Price and Capacity Projections in the Nordic Green Certificate Market, FCN Working Paper No. 16/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Weibel S., Madlener R. (2013). Cost-effective Design of Ringwall Storage Hybrid Power Plants: A Real Options Analysis, FCN Working Paper No. 17/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Budny C., Madlener R., Hilgers C. (2013). Economic Feasibility of Pipeline and Underground Reservoir Storage Options for Power-to-Gas Load Balancing, FCN Working Paper No. 18/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Johann A., Madlener R. (2013). Profitability of Energy Storage for Raising Self-Consumption of Solar Power: Analysis of Different Household Types in Germany, FCN Working Paper No. 19/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Hackbarth A., Madlener R. (2013). Willingness-to-Pay for Alternative Fuel Vehicle Characteristics: A Stated Choice Study for Germany, FCN Working Paper No. 20/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Katatani T., Madlener R. (2013). Modeling Wholesale Electricity Prices: Merits of Fundamental Data and Day-Ahead Forecasts for Intermittent Power Production, FCN Working Paper No. 21/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Baumgärtner M., Madlener R. (2013). Factors Influencing Energy Consumer Behavior in the Residential Sector in Europe: Exploiting the REMODECE Database, FCN Working Paper No. 22/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Charalampous G., Madlener R. (2013). Risk Management and Portfolio Optimization for Gas- and Coal-Fired Power Plants in Germany: A Multivariate GARCH Approach, FCN Working Paper No. 23/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Mallah S., Madlener R. (2013). The Causal Relationship Between Energy Consumption and Economic Growth in Germany: A Multivariate Analysis, FCN Working Paper No. 24/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

2012

Ghosh G., Shortle J. (2012). Managing Pollution Risk through Emissions Trading, FCN Working Paper No. 1/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, January.

Palzer A., Westner G., Madlener M. (2012). Evaluation of Different Hedging Strategies for Commodity Price Risks of Industrial Cogeneration Plants, FCN Working Paper No. 2/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March (revised March 2013).

Sunak Y., Madlener R. (2012). The Impact of Wind Farms on Property Values: A Geographically Weighted Hedonic Pricing Model, FCN Working Paper No. 3/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May (revised March 2013).

Achtnicht M., Madlener R. (2012). Factors Influencing German House Owners' Preferences on Energy Retrofits, FCN Working Paper No. 4/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, June.

Schabram J., Madlener R. (2012). The German Market Premium for Renewable Electricity: Profitability and Risk of Self-Marketing, FCN Working Paper No. 5/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Garbuzova M., Madlener R. (2012). Russia's Emerging ESCO Market: Prospects and Barriers for Energy Efficiency Investments, FCN Working Paper No. 6/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July (revised September 2012).

Rosen C., Madlener R. (2012). Auction Design for Local Reserve Energy Markets, FCN Working Paper No. 7/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July (revised March 2013).

Sorda G., Madlener R. (2012). Cost-Effectiveness of Lignocellulose Biorefineries and their Impact on the Deciduous Wood Markets in Germany. FCN Working Paper No. 8/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Madlener R., Ortlieb C. (2012). An Investigation of the Economic Viability of Wave Energy Technology: The Case of the Ocean Harvester, FCN Working Paper No. 9/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Hampe J., Madlener R. (2012). Economics of High-Temperature Nuclear Reactors for Industrial Cogeneration, FCN Working Paper No. 10/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Knaut A., Madlener R., Rosen C., Vogt C. (2012). Effects of Temperature Uncertainty on the Valuation of Geothermal Projects: A Real Options Approach, FCN Working Paper No. 11/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Hünteler J., Niebuhr C.F., Schmidt T.S., Madlener R., Hoffmann V.H. (2012). Financing Feed-in Tariffs in Developing Countries under a Post-Kyoto Climate Policy Regime: A Case Study of Thailand, FCN Working Paper No. 12/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Blass N., Madlener R. (2012). Structural Inefficiencies and Benchmarking of Water Supply Companies in Germany, FCN Working Paper No. 13/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Madlener R., Schabram J. (2012). Predicting Reserve Energy from New Renewables by Means of Principal Component Analysis and Copula Functions, FCN Working Paper No. 14/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Harzendorf F., Madlener R. (2012). Optimal Investment in Gas-Fired Engine-CHP Plants in Germany: A Real Options Approach, FCN Working Paper No. 15/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Schmitz M., Madlener R. (2012). Economic Feasibility of Kite-Based Wind Energy Powerships with CAES or Hydrogen Storage, FCN Working Paper No. 16/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Dergiades T., Madlener R., Christofidou G. (2012). The Nexus between Natural Gas Spot and Futures Prices at NYMEX: Do Weather Shocks and Non-Linear Causality in Low Frequencies Matter?, FCN Working Paper No. 17/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised September 2013).

Rohlfs W., Madlener R. (2012). Assessment of Clean-Coal Strategies: The Questionable Merits of Carbon Capture-Readiness, FCN Working Paper No. 18/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Wüstemeyer C., Bunn D., Madlener R. (2012). Bridging the Gap between Onshore and Offshore Innovations by the European Wind Power Supply Industry: A Survey-based Analysis, FCN Working Paper No. 19/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Fuhrmann J., Madlener R. (2012). Evaluation of Synergies in the Context of European Multi-Business Utilities, FCN Working Paper No. 20/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

2011

Sorda G., Sunak Y., Madlener R. (2011). A Spatial MAS Simulation to Evaluate the Promotion of Electricity from Agricultural Biogas Plants in Germany, FCN Working Paper No. 1/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, January (revised October 2012).

Madlener R., Hauertmann M. (2011). Rebound Effects in German Residential Heating: Do Ownership and Income Matter?, FCN Working Paper No. 2/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Garbuzova M., Madlener R. (2011). Towards an Efficient and Low-Carbon Economy Post-2012: Opportunities and Barriers for Foreign Companies in the Russian Market, FCN Working Paper No. 3/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February (revised July 2011).

Westner G., Madlener R. (2011). The Impact of Modified EU ETS Allocation Principles on the Economics of CHP-Based District Heating Networks. FCN Working Paper No. 4/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Madlener R., Ruschhaupt J. (2011). Modeling the Influence of Network Externalities and Quality on Market Shares of Plug-in Hybrid Vehicles, FCN Working Paper No. 5/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Juckenack S., Madlener R. (2011). Optimal Time to Start Serial Production: The Case of the Direct Drive Wind Turbine of Siemens Wind Power A/S, FCN Working Paper No. 6/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Madlener R., Sicking S. (2011). Assessing the Economic Potential of Microdrilling in Geothermal Exploration, FCN Working Paper No. 7/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Bernstein R., Madlener R. (2011). Responsiveness of Residential Electricity Demand in OECD Countries: A Panel Cointegration and Causality Analysis, FCN Working Paper No. 8/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Michelsen C.C., Madlener R. (2011). Homeowners' Preferences for Adopting Residential Heating Systems: A Discrete Choice Analysis for Germany, FCN Working Paper No. 9/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May (revised January 2012).

Madlener R., Glensk B., Weber V. (2011). Fuzzy Portfolio Optimization of Onshore Wind Power Plants. FCN Working Paper No. 10/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Glensk B., Madlener R. (2011). Portfolio Selection Methods and their Empirical Applicability to Real Assets in Energy Markets. FCN Working Paper No. 11/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Kraas B., Schroedter-Homscheidt M., Pulvermüller B., Madlener R. (2011). Economic Assessment of a Concentrating Solar Power Forecasting System for Participation in the Spanish Electricity Market, FCN Working Paper No. 12/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Stocker A., Großmann A., Madlener R., Wolter M.I., (2011). Sustainable Energy Development in Austria Until 2020: Insights from Applying the Integrated Model "e3.at", FCN Working Paper No. 13/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Kumbaroğlu G., Madlener R. (2011). Evaluation of Economically Optimal Retrofit Investment Options for Energy Savings in Buildings. FCN Working Paper No. 14/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Bernstein R., Madlener R. (2011). Residential Natural Gas Demand Elasticities in OECD Countries: An ARDL Bounds Testing Approach, FCN Working Paper No. 15/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Glensk B., Madlener R. (2011). Dynamic Portfolio Selection Methods for Power Generation Assets, FCN Working Paper No. 16/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Michelsen C.C., Madlener R. (2011). Homeowners' Motivation to Adopt a Residential Heating System: A Principal Component Analysis, FCN Working Paper No. 17/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised January 2013).

Razlaf J., Madlener R. (2011). Performance Measurement of CCS Power Plants Using the Capital Asset Pricing Model, FCN Working Paper No. 18/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Himpler S., Madlener R. (2011). Repowering of Wind Turbines: Economics and Optimal Timing, FCN Working Paper No. 19/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised July 2012).

Hackbarth A., Madlener R. (2011). Consumer Preferences for Alternative Fuel Vehicles: A Discrete Choice Analysis, FCN Working Paper No. 20/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised December 2012).

Heuser B., Madlener R. (2011). Geothermal Heat and Power Generation with Binary Plants: A Two-Factor Real Options Analysis, FCN Working Paper No. 21/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Rohlfs W., Madlener R. (2011). Multi-Commodity Real Options Analysis of Power Plant Investments: Discounting Endogenous Risk Structures, FCN Working Paper No. 22/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised July 2012).

2010

Lang J., Madlener R. (2010). Relevance of Risk Capital and Margining for the Valuation of Power Plants: Cash Requirements for Credit Risk Mitigation, FCN Working Paper No. 1/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Michelsen C.C., Madlener R. (2010). Integrated Theoretical Framework for a Homeowner's Decision in Favor of an Innovative Residential Heating System, FCN Working Paper No. 2/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Harmsen - van Hout M.J.W., Herings P.J.-J., Dellaert B.G.C. (2010). The Structure of Online Consumer Communication Networks, FCN Working Paper No. 3/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Madlener R., Neustadt I. (2010). Renewable Energy Policy in the Presence of Innovation: Does Government Pre-Commitment Matter?, FCN Working Paper No. 4/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April (revised June 2010 and December 2011).

Harmsen - van Hout M.J.W., Dellaert B.G.C., Herings, P.J.-J. (2010). Behavioral Effects in Individual Decisions of Network Formation: Complexity Reduces Payoff Orientation and Social Preferences, FCN Working Paper No. 5/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Lohwasser R., Madlener R. (2010). Relating R&D and Investment Policies to CCS Market Diffusion Through Two-Factor Learning, FCN Working Paper No. 6/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, June.

Rohlfs W., Madlener R. (2010). Valuation of CCS-Ready Coal-Fired Power Plants: A Multi-Dimensional Real Options Approach, FCN Working Paper No. 7/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Rohlfs W., Madlener R. (2010). Cost Effectiveness of Carbon Capture-Ready Coal Power Plants with Delayed Retrofit, FCN Working Paper No. 8/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August (revised December 2010).

Gampert M., Madlener R. (2010). Pan-European Management of Electricity Portfolios: Risks and Opportunities of Contract Bundling, FCN Working Paper No. 9/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Glensk B., Madlener R. (2010). Fuzzy Portfolio Optimization for Power Generation Assets, FCN Working Paper No. 10/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Lang J., Madlener R. (2010). Portfolio Optimization for Power Plants: The Impact of Credit Risk Mitigation and Margining, FCN Working Paper No. 11/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Westner G., Madlener R. (2010). Investment in New Power Generation Under Uncertainty: Benefits of CHP vs. Condensing Plants in a Copula-Based Analysis, FCN Working Paper No. 12/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Bellmann E., Lang J., Madlener R. (2010). Cost Evaluation of Credit Risk Securitization in the Electricity Industry: Credit Default Acceptance vs. Margining Costs, FCN Working Paper No. 13/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September (revised May 2011).

Ernst C.-S., Lunz B., Hackbarth A., Madlener R., Sauer D.-U., Eckstein L. (2010). Optimal Battery Size for Serial Plug-in Hybrid Vehicles: A Model-Based Economic Analysis for Germany, FCN Working Paper No. 14/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October (revised June 2011).

Harmsen - van Hout M.J.W., Herings P.J.-J., Dellaert B.G.C. (2010). Communication Network Formation with Link Specificity and Value Transferability, FCN Working Paper No. 15/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Paulun T., Feess E., Madlener R. (2010). Why Higher Price Sensitivity of Consumers May Increase Average Prices: An Analysis of the European Electricity Market, FCN Working Paper No. 16/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Madlener R., Glensk B. (2010). Portfolio Impact of New Power Generation Investments of E.ON in Germany, Sweden and the UK, FCN Working Paper No. 17/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Kwasnica A., Shortle J. (2010). A Laboratory Experiment to Compare Two Market Institutions for Emissions Trading, FCN Working Paper No. 18/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Bernstein R., Madlener R. (2010). Short- and Long-Run Electricity Demand Elasticities at the Subsectoral Level: A Cointegration Analysis for German Manufacturing Industries, FCN Working Paper No. 19/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Mazur C., Madlener R. (2010). Impact of Plug-in Hybrid Electric Vehicles and Charging Regimes on Power Generation Costs and Emissions in Germany, FCN Working Paper No. 20/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Madlener R., Stoverink S. (2010). Power Plant Investments in the Turkish Electricity Sector: A Real Options Approach Taking into Account Market Liberalization, FCN Working Paper No. 21/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised July 2011).

Melchior T., Madlener R. (2010). Economic Evaluation of IGCC Plants with Hot Gas Cleaning, FCN Working Paper No. 22/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Lüschen A., Madlener R. (2010). Economics of Biomass Co-Firing in New Hard Coal Power Plants in Germany, FCN Working Paper No. 23/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised July 2012).

Madlener R., Tomm V. (2010). Electricity Consumption of an Ageing Society: Empirical Evidence from a Swiss Household Survey, FCN Working Paper No. 24/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Tomm V., Madlener R. (2010). Appliance Endowment and User Behaviour by Age Group: Insights from a Swiss Micro-Survey on Residential Electricity Demand, FCN Working Paper No. 25/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Hinrichs H., Madlener R., Pearson P. (2010). Liberalisation of Germany's Electricity System and the Ways Forward of the Unbundling Process: A Historical Perspective and an Outlook, FCN Working Paper No. 26/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Achtnicht M. (2010). Do Environmental Benefits Matter? A Choice Experiment Among House Owners in Germany, FCN Working Paper No. 27/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

2009

Madlener R., Mathar T. (2009). Development Trends and Economics of Concentrating Solar Power Generation Technologies: A Comparative Analysis, FCN Working Paper No. 1/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised September 2010).

Madlener R., Latz J. (2009). Centralized and Integrated Decentralized Compressed Air Energy Storage for Enhanced Grid Integration of Wind Power, FCN Working Paper No. 2/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised September 2010).

Kraemer C., Madlener R. (2009). Using Fuzzy Real Options Valuation for Assessing Investments in NGCC and CCS Energy Conversion Technology, FCN Working Paper No. 3/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Westner G., Madlener R. (2009). Development of Cogeneration in Germany: A Dynamic Portfolio Analysis Based on the New Regulatory Framework, FCN Working Paper No. 4/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised March 2010).

Westner G., Madlener R. (2009). The Benefit of Regional Diversification of Cogeneration Investments in Europe: A Mean-Variance Portfolio Analysis, FCN Working Paper No. 5/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised March 2010).

Lohwasser R., Madlener R. (2009). Simulation of the European Electricity Market and CCS Development with the HECTOR Model, FCN Working Paper No. 6/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Lohwasser R., Madlener R. (2009). Impact of CCS on the Economics of Coal-Fired Power Plants – Why Investment Costs Do and Efficiency Doesn't Matter, FCN Working Paper No. 7/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Holtermann T., Madlener R. (2009). Assessment of the Technological Development and Economic Potential of Photobioreactors, FCN Working Paper No. 8/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Carriazo F. (2009). A Comparison of Three Methods of Estimation in the Context of Spatial Modeling, FCN Working Paper No. 9/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Shortle J. (2009). Water Quality Trading when Nonpoint Pollution Loads are Stochastic, FCN Working Paper No. 10/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Ribaudo M., Shortle J. (2009). Do Baseline Requirements hinder Trades in Water Quality Trading Programs?, FCN Working Paper No. 11/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Madlener R., Glensk B., Raymond P. (2009). Investigation of E.ON's Power Generation Assets by Using Mean-Variance Portfolio Analysis, FCN Working Paper No. 12/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

2008

Madlener R., Neustadt I., Zweifel P. (2008). Promoting Renewable Electricity Generation in Imperfect Markets: Price vs. Quantity Policies, FCN Working Paper No. 1/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July (revised November 2011).

Madlener R., Wenk C. (2008). Efficient Investment Portfolios for the Swiss Electricity Supply Sector, FCN Working Paper No. 2/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Omann I., Kowalski K., Bohunovsky L., Madlener R., Stagl S. (2008). The Influence of Social Preferences on Multi-Criteria Evaluation of Energy Scenarios, FCN Working Paper No. 3/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Bernstein R., Madlener R. (2008). The Impact of Disaggregated ICT Capital on Electricity Intensity of Production: Econometric Analysis of Major European Industries, FCN Working Paper No. 4/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Erber G., Madlener R. (2008). Impact of ICT and Human Skills on the European Financial Intermediation Sector, FCN Working Paper No. 5/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

FCN Working Papers are free of charge. They can mostly be downloaded in pdf format from the FCN / E.ON ERC Website (www.eonerc.rwth-aachen.de/fcn) and the SSRN Website (www.ssrn.com), respectively. Alternatively, they may also be ordered as hardcopies from Ms Sabine Schill (Phone: +49 (0) 241-80 49820, E-mail: post_fcn@eonerc.rwth-aachen.de), RWTH Aachen University, Institute for Future Energy Consumer Needs and Behavior (FCN), Chair of Energy Economics and Management (Prof. Dr. Reinhard Madlener), Mathieustrasse 10, 52074 Aachen, Germany.