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COST-BENEFIT ANALYSIS OF A TRANSPORT IMPROVEMENT IN THE CASE OF SEARCH UNEMPLOYMENT[1]

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ABSTRACT

We examine the implications of search unemployment for the evaluation of a transport investment in a conventional cost benefit analysis (CBA) assuming perfect competition. Lower transport costs induces search over a larger area and longer commuting distances. The expected duration of vacancies is reduced with ensuing benefits outweighing the loss to increased transport. The search imperfection drives a wedge between the marginal product of labour and the wage, such that the final benefits of a transport improvement exceed those of a conventional CBA. Using a simulation model we find these additional benefits may be substantial.

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1.0 INTRODUCTION

The purpose of this paper is to investigate the effects of a labour market search imperfection on the results of a conventional cost-benefit analysis (CBA) of a transport improvement. Conventional CBA generally assumes perfect competition in non-transport sectors. This is convenient since it allows the analysis to be based on the market for transport alone, considering only the direct transport impacts.

However, with imperfect competition in non-transport sectors it is no longer adequate to base the analysis only on the market for transport. There will be effects on other markets such as those for housing, labour and goods (Kidokoro 2004) that may be significant for the conclusion of the analysis. Thus, as noted by DETR (1999), the value of the direct transport impacts will not be the same as the value of final economic impacts. Therefore, conventional CBA may be misleading when the effects of market imperfections are large.

A potentially significant imperfection occurs in labour markets, which are characterised by the presence of unemployment. This paper formulates a small spatial computable general equilibrium (CGE) model with a labour market search imperfection leading to unemployment. We implement a transport improvement in this model and compare the full welfare effect under the model to the effect that would be obtained from a conventional CBA. Thus the contribution of this paper is to point out the potential significance of labour market effects relative to the conventional CBA. We find that additional labour market benefits may be substantial in relation to the direct user benefits.

This paper adds to a growing literature on imperfections relative to conventional CBA. These studies are rooted in New Economic Geography, see for example Krugman (1991) and Fujita *et al* (2000). Venables and Gasiorek (1999) examine imperfect competition in the transport using sector in a regional model. Industries exhibit increasing returns to scale and a transport cost reduction leads to industry rationalisation. Furthermore they include pro-competitive effects as firms can more easily compete in different regions when transport costs are reduced. Finally they study effects of linkages and agglomeration between firms and industrial and regional heterogeneity. Using constructed data they find that the real income gains from transport improvements typically exceed those computed by the standard CBA technique by 30-50 per cent, where the magnitude depends on different assumptions and parameters.

Venables (2007) argues in favour of productivity effects related to agglomeration. City size is regulated by two opposing forces: First, workers are more productive in a larger city which leads to agglomeration. Second, this force is balanced by the increase in commuting costs due to congestion. When congestion costs are reduced, the city may become larger and productivity may increase. The productivity increase is additional to the benefits accounted for in conventional CBA. This effect is reinforced by distortionary income taxation, which drives a wedge between the marginal product of labour and the net wage. Venables finds with some qualifications that the total benefit of reducing commuting costs may be several times larger than the reduction in commuting costs.

In this paper we introduce unemployment and let workers decide the area over which to search based on commuting costs. A reduction in commuting costs induces unemployed workers to search over larger areas. This reduces the average duration of unemployment spells and hence leads to increased employment.

Thus we have several sources of additional benefits relative to conventional CBA. Each may be quantitatively significant. An important question is then how these sources interact. We will seek to provide some intuition on this issue in our concluding remarks, but we focus on illustrating the effect of the labour market search imperfection. Hence we do not include the complication of other imperfections on our model.

The layout of this paper is as follows. In section 2.0 we provide a more detailed discussion of search unemployment in relation to transport. Section 3.0 introduces the CGE model and in section 4.0 we discuss the effects that are found in the CGE model compared to the effects covered by the standard CBA in the case of an infrastructure investment. Section 5.0 reports some simulation results. Finally section 6.0 concludes.

2.0 SEARCH IMPERFECTIONS ON THE LABOUR MARKET AND TRANSPORT

It is a prominent feature of the labour market that it is in a state of permanent flux. Jobs are constantly being destroyed while new jobs are created elsewhere. For US manufacturing during 1973-1988, Davis et al. (1997) finds that 10.3 per cent of all jobs are destroyed annually, while at the same time 9.1 per cent new jobs are created elsewhere. The difference reflects decreasing total employment in US manufacturing during that period. For Denmark, Albæk and Sørensen (1998) finds even higher rates of job turnover during 1980-1991: at least 12 per cent new jobs are created while 11.5 per cent of the existing jobs are destroyed. This creates large gross flows in and out of jobs. The average worker has a high probability of experiencing an unemployment spell.

Workers and firms do not have perfect information. Therefore it takes a while for unemployed workers and jobs to match, even though there is simultaneously unemployment and vacant jobs. This form of unemployment is termed search unemployment and is an important part of structural unemployment. This labour market imperfection can be seen to be fairly important considering that the structural unemployment rate is well above zero in most countries.

Search unemployment has been studied by several authors, notably Pissarides (1990, 2000) who presents a consistent equilibrium theory of search unemployment. This framework is applied in this paper.

Search imperfections on the labour market are closely linked to transport. The fundamental imperfection causing unemployment is the lack of the information necessary in order to clear the labour market at each instant. Search imperfections may have as a consequence that there may be more commuting than would be the case under perfect information. This implies a loss relative to the case of perfect competition. Furthermore, changes in transport costs may affect the size of this loss with implications for cost-benefit analysis. The basic intuition of this is the following.

In a perfect competition world, a worker would have full information and choose his job optimally. In this world we could infer that his additional benefit of accepting a job far away rather than near to home outweighs his additional commuting costs, since otherwise he would not have accepted the job with higher commuting costs. This observation is at the heart of standard welfare economic analysis of transport investments under the assumption of perfect competition.

This conclusion is no longer valid when we allow for a search imperfection. When a worker becomes unemployed, he must decide how far away he is willing to search for a job. But now this involves a choice between uncertain alternatives. If the worker chooses to search only locally, he does not risk incurring high commuting costs but the expected duration of his unemployment spell may be long. Conversely, if he increases his search area he may reduce the expected duration of his unemployment spell at the cost of a risk of incurring higher commuting costs. On balance we may assume that the worker chooses his search area such as to balance the benefit of reducing the expected duration of unemployment with the expected cost of commuting.

The worker chooses his ex ante search strategy optimally but the ex post outcome may not be optimal. It may happen that a worker accepts a remote job with high commuting costs, while a nearby job with lower commuting costs would entail a higher net utility.

Thus an investment leading to reduced commuting costs may lead to increased commuting which entails a cost, not a benefit as would be inferred assuming perfect competition. The loss from increased commuting is offset by reduced duration of unemployment spells and hence a reduced level of unemployment.

3.0 THE MODEL

We formulate a general equilibrium model describing, in principle, the behaviour of all relevant agents of the economy. The equilibrium conditions of all markets are fully described such that the second order effects of a given policy change are included. The model is formulated dynamically and solved in steady state.

The model describes commuting transport in a small open economy with two identical regions characterized by search imperfections on the labour market (following Pissarides (2000)).[2] The agents in the model are utility-maximising households/workers, profit-maximising firms and a government. There is also a union in each region which negotiates the local wage. The model is described in the following sections.

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[2] This model was used in another version in Pilegaard (2003).

3.1 The Households

We identify a household with a worker, who consumes goods, c, and pure leisure, l. There is a continuum of workers, indexed by $\nu \in [0:1]$ living in each region. At the same time, we take ν as the individual exogenous evaluation of pure leisure relative to consumption and consequently also the individual value of time. We assume a separable linear utility function

$$u_\nu(c,l) = c + \nu \cdot l \text{ .} \tag{1}$$

The consumption of goods and leisure is restricted by budget constraints for time and money. The demand for commuting emerges from the need to go to work to earn the wage w, and thereby increase the consumption of goods. A worker can be employed in his residential region or in the neighbouring region. Job characteristics are identical in the two regions but commuting to the neighbouring region is more time consuming than commuting to a job in the residential region since the distance is longer. To simplify we assume that a worker has only commuting costs associated with commuting time from region i to region j, denoted by $l_{i,j}^{com}$.

We assume that goods are consumed instantaneously without any use of time. Therefore, the total time endowment, $\bar{l}$, is spent working the hours a, on commuting and on leisure. The residual leisure for a worker living in region i is given by:

$$l = \begin{cases} l^e{}_{i,j} = \bar{l} - a - l_{i,j}^{com} & \text{if employed in region } j \\ l_i^u = \bar{l} & \text{if unemployed} \end{cases} \tag{2}$$

All workers receive a lump sum transfer τ from the government and unemployed workers additionally receive the benefit b. There is no income tax in the model as it would obscure the main insights of interest. Letting p^c be the consumer price on consumption goods, the money budget restriction for a worker living in region i is therefore given by:

$$c = \begin{cases} C_{i,j}^{e} = \dfrac{w_j + \tau}{p^c} & if\ \ employed\ in\ region\ j \\ C_{i}^{u} = \dfrac{b + \tau}{p^c} & if\ \ unemployed \end{cases} \tag{3}$$

A worker who searches for a job in region *j* finds employment in *j* at the rate ρ_j. At the same time, the employed workers in *j* are laid off from work at the rate s_j. These transition rates are the same for all workers and hence everybody experiences both employment and unemployment at some point in time. The model excludes on-the-job search and a job change therefore only takes place after a worker has been laid off.

An unemployed worker must choose a search strategy among two possibilities: under strategy *h* he only searches for a job in the region where he is resident, while under strategy *b* he searches in both regions. Under strategy *h,* he will never incur the high commuting costs, but the expected duration of unemployment is longer.

A worker chooses a search strategy to maximise the expected present value of his future utility using the discount rate δ. We can determine the value ν_i* of ν that makes a worker living in region *i* indifferent between the two search strategies by equating the expected present values under the two strategies. This ν_i* is determined by the relation

$$\nu_i * = \frac{C_{i,j}^{e} - C_{i}^{u}}{l_i^u - l_{i,j}^e + \dfrac{\rho_i}{\delta + s_i} \cdot (l_{i,i}^e - l_{i,j}^e)} . \tag{4}$$

For any $\nu > \nu_i^*$, that is, for any worker in *i* with a higher valuation of leisure, it will be preferable to search only in the region where he is resident. The opposite holds for the consumers with $\nu < \nu_i^*$. [3]

The numerator in (4), $C_{i,j}^e - C_i^u$, is the gain in consumption from being employed in the neighbouring region compared to being unemployed. Similarly, the denominator equals the total discounted expected loss in leisure of being employed in the neighbouring region relative to being unemployed and searching only locally. When determining whether to search in the neighbouring region or not, the surplus (or loss) of getting a job in the neighbouring region is compared to the expectation of the surplus of being employed in the residential region. Hence, the probability of being employed in the neighbouring region does not affect ν_i^*. Basically, the worker trades off the additional commuting time with the chance of reducing the unemployment spell.

3.2 The Firms

Firms produce with labour as the only input and decreasing marginal productivity. The representative firm in *i* lays off employees at the exogenous rate s_i as described earlier. When firms want to hire more workers they have to open vacancies. A vacancy is paired with an unemployed worker at the rate q_i. The vacancies, O_i, are costly to the firms; each has a fixed cost, σ_2.

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[3] We have assumed that the regions are identical, that jobs have the same characteristics and that commuting costs are only related to the use of time. Relaxing these assumptions will affect the expression for ν_i^*.

The firms are small without market power. This implies that they take the output price as given. The workers are homogenous from the firms' point of view, no matter where they live. Therefore, a firm is only interested in its total number of workers, N_i. The change in a firm's employment from one period to the next is given by the number of newly employed workers minus the number of laid off workers. The number of firms in each region is normalised to 1 with no loss of generality.

We assume a small open economy. A perfect substitute for the domestically produced consumption commodity is produced abroad at the world market price. The output price of the firms is therefore exogenous.

The problem for a representative firm located in region i is to choose the number of job openings to maximise the present value of expected future profits given the dynamic change in employment. Solving the firm's problem leads to the steady state first order condition saying that the firms employ workers until the value of the marginal product of labour equals the sum of the wage and the expected value of production losses caused by laying off workers and hiring costs. This implies that the imperfections in the labour market drive a wedge between the value of the marginal product and the wage.

3.3 Matching Workers and Jobs

Since the firms consider all workers as homogenous, all unemployed workers searching for a job in a region have the same probability of being hired in this region. At any point in time, the number of matches M_i, or the number of newly occupied jobs in region i, is assumed to be a function of the number of unemployed workers looking for a job in region i, the job candidates Z_i , and the number of vacancies. We assume that these are matched by a Cobb-Douglas technology, $M_i = \phi_i \cdot Z_i^{\eta_i} \cdot O_i^{1-\eta_i}$, where ϕ_i is a parameter.

The rate at which a firm gets a vacant job occupied, q_i , is the ratio of job matches to job openings: $M_i / O_i \equiv q_i$. The more candidates relative to job openings, the easier it is for the firms to get the job matched and the shorter is the expected duration of the vacancy, $1/q_i$. Similarly, the rate at which the unemployed workers find jobs in region i is given by the ratio of matches to job candidates: $M_i / Z_i \equiv \rho_i$. The more job openings relative to job candidates, the easier it is for an unemployed worker to find work and the shorter is the expected duration of the unemployment spell, $1/\rho_i$.

The unemployment of workers depends on where they live and their search strategy (h or b). U_i^h is the number of unemployed workers living in i searching only in their residential region while U_i^b is the number of unemployed workers living in i and searching in both regions. $N_{i,i}{}^h$ and $N_{i,j}{}^b$ are the corresponding numbers of workers employed in i and j with each search strategy. The change in unemployment for the group of workers with a given search behaviour is the sum of the number of newly laid off workers minus the number of newly hired workers. In steady state this change must equal zero such that the number of unemployed workers equals the average number of laid off workers times the average length of an unemployment spell.

$$
\begin{aligned}
U_i^h &= \frac{s_i \cdot N_{i,i}^h}{\rho_i} \\
U_i^b &= \frac{\sum_j s_j \cdot N_{i,j}^b}{\sum_j \rho_j}
\end{aligned}
\qquad (5)
$$

Similarly one can find the steady state employment for the groups of workers:

$$
\begin{aligned}
N_{i,i}^h &= \frac{\rho_i \cdot U_i^h}{s_i} \\
N_{i,j}^b &= \frac{\rho_j \cdot U_i^b}{s_j}
\end{aligned}
\qquad (6)
$$

Since all workers with $\nu<\nu_i$* will search in both regions while workers with $\nu>\nu_i$* will search only in their region of residence, the equilibrium conditions for the groups of workers are given by:

$$\begin{aligned} N_{i,i}^{b} + N_{i,j}^{b} + U_{i}^{b} &= \nu_{i}* \\ N_{i,i}^{h} + U_{i}^{h} &= 1 - \nu_{i}* \end{aligned} \qquad (7)$$

3.4 Wage Formation

It is assumed that the wage is determined in a Nash bargaining process between the firms and a representative union member who negotiates a single wage that does not compensate for differences in commuting costs. Therefore, we may assume that the union member represents only the resident workers, who are also the majority of the labour force in the region.

In the bargaining they share the benefits that occur when a vacant worker and a vacancy is matched. Therefore, the wage will deviate both from the marginal cost of labour and from the reservation costs of the workers, that is the costs of being employed relative to being unemployed.

Even though wage formation is endogenous, changes in commuting costs will cause real utility changes both for intra- and inter-regional commuters; inter-regional commuters because they cover the commuting costs themselves; intra-regional commuters through the benefit sharing in the wage bargaining process.

3.5 The Government

The government supplies a public good, raises taxes and pays benefits to the unemployed workers. The government raises taxes from commodity consumption and expropriates all profits from the firms. Finally, the government balances the budget with a lump sum transfer to all workers in the economy.

The supply of the public good is assumed constant and it does not increase the utility of the workers. The government finances the transport infrastructure, which is free for use. It is assumed that the costs of maintaining the infrastructure are constant and independent of use or, alternatively, that the public consumption in total is constant and that increases in road infrastructure maintenance costs are counterbalanced by a cut in other public consumption.

4.0 WELFARE ECONOMIC ANALYSIS

Having formulated the economic model, we proceed by defining an infrastructure investment for which the welfare economic analysis is performed.

4.1 An Infrastructure Investment

We assume that the interregional road is improved such that the interregional commuting time is reduced by 10 per cent. To simplify the analysis we assume that the investment is financed via the lump sum tax. Since this tax is non-distortionary we can simply set the investment cost to zero. This allows us to focus on the benefits of the investment and is no restriction on results.

4.2 Illustration of the difference between CGE and CBA Results

In applied CBA, the assumption is routinely made that benefits to travellers is represented by the change in consumer surplus, that is the change in the areas below the demand curves for each link in a network (Kidokoro 2004). This benefit comprises the cost saving to existing travellers plus an additional benefit to newly generated travellers. This is illustrated by the areas of *a* and *b* in Figure 1. This assumption may be justified by the assumption of perfect competition (see for example Jara-Diaz 1986, Fosgerau and Kristensen 2005). Given our assumptions, the direct effect of a transport investment consists only of the change in transport demand. There is no direct effect on the government revenue or behaviour of the firms. Thus, the CBA in our model consists only of the consumer's surplus (CS).

However, when search unemployment is considered, this conclusion is no longer valid. There are two main modifying effects. Both may be substantial and they can plausibly overshadow the consumer surplus.

The first effect is that the transport improvement will induce workers who become unemployed to search over a larger area. In equilibrium, a proportion of the new travellers on the improved link will then have exchanged a local job for a job further away from home. For the individual long distance commuting worker, this in itself entails no benefits, but instead a cost consisting of the difference in commuting cost between working locally and further away.

However, the second effect is that the increased search activity reduces the unemployment rate by shortening the average duration of unemployment spells. This entails a benefit for each additional person who becomes employed for this reason as well as increased tax payments. Depending on the increase in employment this second effect may entail a large benefit.

Figure 2 a and b illustrate the effects for the employed and unemployed workers of an interregional commuting cost reduction in the situation with job search imperfections. In this example we set the regional commuting costs to zero. To further simplify the figures they illustrate only partial effects, without general equilibrium reactions to prices and labour market responses on durations. The demand curves are approximated by straight lines.

Figure 2a illustrates how the distribution of workers from region *i* depends on the inter-regional commuting costs. The number of both actual and potential interregional commuters ($N^b_{i,j}, N^b_{i,i}$ and U^b_i) is decreasing in interregional commuting costs, while the number of employed and unemployed workers who will work only in their residential region is increasing in interregional commuting costs. $N^b_{i,j}$ is the demand for inter-regional transport. In standard CBA we would just compute the change in the area under this curve.

In Figure 2b we add the effects of reducing the interregional commuting costs (from ${l^{com}_{i,j}}^0$ to ${l^{com}_{i,j}}^1$). The ex ante number of commuters $N^{b,0}_{i,j}$ experience a saving of $\Delta l^{com}_{i,j}$, this benefit is represented by the square *a*. The number of interregional commuters increases when the interregional commuting costs are reduced. The new commuters, $N^{b,1}_{i,j} - N^{b,0}_{i,j}$, pay the additional commuting cost of ${l^{com}_{i,j}}^1$. This is a loss since before they were resident workers and thus had zero commuting costs. The triangle *b* has no effect on the welfare. The increased search activity implies that the level of employment increases (by ΔN). This generates a social gain since the marginal product of labour is higher than the private cost of working. The total welfare effect of the commuting cost reduction is therefore the gain for the existing commuters (*a*) plus the net gain of the additional employment (d) minus the additional commuting costs for the new long distance commuters (*c*).

The driver of the results here is that the increased willingness to search in the neighbouring region increases the total employment. This can easily be seen in the Figure 2 since $N^b_{i,j} + N^b_{i,i} + N^h_{i,i}$ is decreasing in $l^{com}_{i,j}$. Thus, the increase in employment among workers who are now willing to work in the neighbouring region, is larger than the reduction in employment of workers, who are willing to work only in the residential region. This is the same as to say that the total unemployment decreases. Total unemployment *U* is the sum of unemployment of workers who are willing to search in both regions and who are only willing to search residentially: $U_i = U_i^b + U_i^h$. Using equations (5**Error! Reference source not found.**) and (6) the number of unemployed workers in each of the groups is given by:

$$\left.\begin{aligned} U_i^h + N_{i,i}^h &= 1 - \nu_i * \\ U_i^b + N_{i,i}^b + N_{i,j}^b &= \nu_i * \end{aligned}\right\} \Rightarrow \begin{cases} U_i^h = \dfrac{s}{s+\rho}\left(1-\nu_i *\right) \\ U_i^b = \dfrac{s}{s+2\rho}\nu_i * \end{cases} \tag{8}$$

Since a decrease in interregional travel costs ($l_{i,j}^{com}$) increases ν_i* it is now easy to see that the total effect on unemployment of a travel cost reduction is negative.

$$\frac{dU_i}{dl_{i,j}^{com}} = \left(\frac{s}{s+2\rho} - \frac{s}{s+\rho}\right)\frac{d\nu_i *}{dl_{i,j}^{com}} > 0 \tag{9}$$

The social benefit of an additional worker being employed instead of being unemployed is the marginal product of labour minus the value of working time for the marginal worker. As described earlier, the marginal product of labour is higher than the real wage since the firms have to take into account their search costs of hiring new workers when determining on their employment level.

When we expand the analysis to include general equilibrium effects we will also see reactions in the matching rates ρ and q. This changes the slopes of the curves in the figure and will typically reduce the effects. We find in our application, that the equilibrium effects on the duration of an unemployment period and a vacancy are small which implies that the induced effects on the curves would be small as well.

4.3 Welfare Effects

In the CGE model, the welfare effects can be measured by the Equivalent Variation (EV). EV measures the money transfer (positive or negative) that a consumer should receive in the initial situation to be indifferent between accepting this transfer and experiencing the policy change.

In this simple CGE model, the EV is found by:

$$EV = (\bar{u}^1 - \bar{u}^0)p^{C0} \qquad (10)$$

where $\bar{u}$ is the average total utility that the consumers experience and $p^{c,0}$ is the initial consumer price level. Here the EV is defined as the per period payment and not as a one-time total payment. Therefore, we also calculate the consumer surplus per period.

4.4 Calculating the Consumers Surplus

When calculating the CS it is normally assumed that the demand curve for travel is approximately linearly downward sloping in generalised travel costs. Letting N^0 and l^0 respectively N^1 and l^1 be the number of travellers and the travel time before respectively after the policy change and *VoT* be the value of time. Then the CS is calculated using the rule of-a-half.

$$CS = ½ \cdot (l^0 - l^1) \cdot VoT \cdot \left(N^1 + N^0\right) \qquad (11)$$

In this approximation it is assumed that the value of time is identical – or identically distributed – for all travellers. However, each traveller has an individual value of time in our model and the average *VoT* for a group of travellers changes systematically when the group of travellers changes. Therefore it is problematic to assume a constant average VoT. In a better approximation the individual value of time must to be taken into account.

In the appendix we show that when the distribution of the individual values of time is taken into account, then the CS in our model may be approximated by:

$$CS_{i,j} = ½ \cdot (l_{i,j}^{com^0} - l_{i,j}^{com^1}) \cdot \left(N_{i,j}^{b\ 1} \cdot VoT^1 + N_{i,j}^{b\ 0} \cdot VoT^0 \right) \qquad (12)$$

5.0 EMPIRICAL ILLUSTRATION

5.1 The Simulation Model

In order to implement the model, we insert numbers such that the model reproduces some main features of the Danish Economy. Here, we give a brief overview of the main parameters.

The time period is one year. The number of workers in each region is normalised to 1. We fix the interest rate at r=0.08, the discount factor at δ=0.1 and the rate with which workers are laid off at s=0.1. The matching parameter is chosen to be η=0.65, which implies that the negative externalities firms cause each other are larger than the negative externalities that searching workers cause each other. The interregional commuting time per work day is 94 minutes per day, while the intraregional commuting time is 40 minutes per day. In the model, 28.7 per cent of workers commute ex ante and the ex ante unemployment rate is 6 per cent. The rate of consumption tax is set to 25 per cent, which is the current rate of VAT in Denmark.

The ex ante output per region is 450,000 DKK[4] per year, which is close to the actual Danish GDP per worker. The ex ante wage is 180,000 DKK, the lump sum transfer is 17,500 DKK and the unemployment benefit is 36,300 DKK per year. The ex ante consumption per

[4] 1 Euro = 7.5 DKK.

region of 190,000 DKK per year is equal to the actual Danish annual private consumption per worker.

5.3 Results

In table 1 we report the results of a 10 per cent reduction in interregional commuting time in the model. The welfare effects are calculated both as EV and as the direct effects in a CBA (CS). We have calculated the CS taking into account the individual value of time using (12).

The consumer surplus per person is 246 DKK, while the equivalent variation is 318 DKK.[5] Thus, this simulation indicates substantial indirect effects of 29 per cent on top of the consumer surplus.

It is informative to decompose the CS and the EV into parts: the direct effect of the travel time change and the indirect effects. The CS consists of a direct travel time benefit to ex ante commuters of 228 DKK plus a benefit to new commuters of 18 DKK, the latter corresponding to area (*b*) in Figure 1. In the EV calculation, the benefit to new commuters is replaced by a loss due to additional commuting time costs of 181, corresponding to area (*c*) in Figure 1.

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[5] We can roughly relate the consumer surplus to the commuting time saving as follows. A worker commutes 225 days per year and the daily two-way commuting time for inter-regional commuters is 94 minutes, which is reduced by 10 per cent. The 28.7 per cent of the population who are inter-regional commuters have ex ante an average value of time of 22.6 DKK per hour; this value is low since it is the workers with the lowest value of time who commute inter-regionally in the model. With these numbers we would find a total value of the travel time reduction of 228 DKK per person.

However, this loss is more than compensated by the indirect effects. Increased consumption leads to a gain of 415 DKK, while increased employment leads to a loss of leisure worth 143 DKK, leading to a total indirect effect of 271 DKK.

5.4 Sensitivity

The figures in Table 1 result from a single set of parameters. The exact relation between EV and CBA depends on many aspects in the details of the model formulation as well as the calibration. However, a larger wedge between the real wage and the marginal product of labour generally increases the ratio between the EV and the CS. A higher value of time increases directly all elements of the benefit calculation that are related to time, while the share from consumption goods in the EV calculation is unaffected by first order effects. As the sum of these is negative in the EV and positive in CS, an increase in the value of time will then reduce the ratio between the EV and the CS.

6.0 CONCLUDING REMARKS

In this paper we have found that in a situation where the labour market is subject to search imperfection there could be substantial welfare effects omitted when evaluating the effects of an infrastructure improvement only by the direct transport cost effects.

The general level of structural employment in most countries suggests that the omitted effects are in fact important and deserve more attention. A vital task is then to provide more empirical evidence with the ultimate goal of including labour market imperfections in project evaluation.

It is an important feature of the model that it explicitly takes into account the relation between transport and the labour market, something which is often seen as central by politicians, but which conventional cost-benefit analysis fails to do.

An important driver for the result that the equivalent variation is higher than the consumer surplus of the conventional CBA, is that the marginal productivity of a worker is higher than the real wage. This implies that there are benefits of increased employment that the individuals do not take into account. This difference between the real wage and the marginal product of labour is a consequence of the search imperfection in our model.

A difference between the marginal product of labour and the real wage is also found in other models with imperfections on the labour market; for example when there is a positive labour income tax or if there are agglomeration productivity effects. In such a model there will also be benefits of employment that the individual worker does not take into account when deciding his behaviour and therefore it would also be the case that the EV exceeds the direct effects covered by the CBA (Venables 2007).

One may ask what is the interaction between the effect of the search imperfection described in this paper and the agglomeration benefits described by Venables (2007).[6] We suggest the interaction will be positive for the following reason. Consider a large city with agglomeration productivity effects as one of the regions in our model. If the commuting costs to the large city are reduced, then the reduction in search employment will increase employment in the city. The cost reduction also leads to increased employment in the city due to the agglomeration effect. But the increase in employment in the city due to the decrease in general

[6] This issue was raised by a referee.

unemployment will increase the level from which the agglomeration effect acts. Thus there is a second order effect which can be expected to be positive.

Our model assumes that labour is homogenous, but increasing specialisation of the labour force is argued to be a driver behind the tendency toward increased commuting distances observed in many countries. With differences in job characteristics a worker would face an additional trade-off between job characteristics and commuting costs. However, the wedge between the marginal product of labour and the real wage will still be present, such that the equivalent variation would still exceed the consumer surplus. A transport improvement may lead to increased quality of the matches and hence increased productivity if workers possess different skills, which would entail a further benefit.

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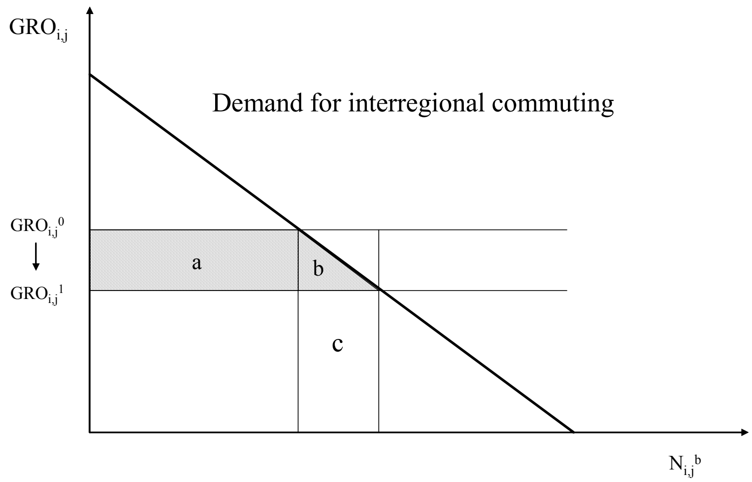

Figure 1: Perfect competition

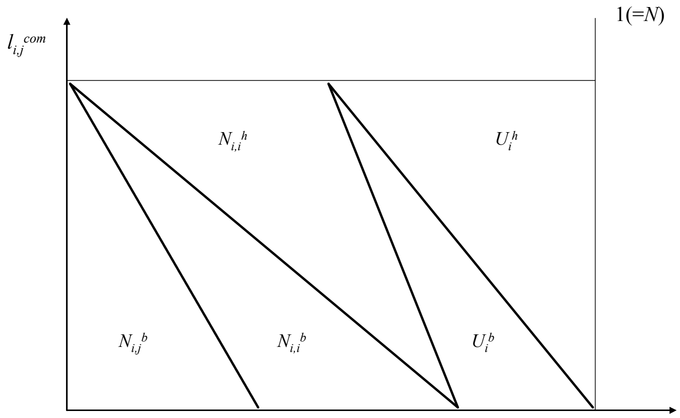

Figure 2a: Job search imperfections

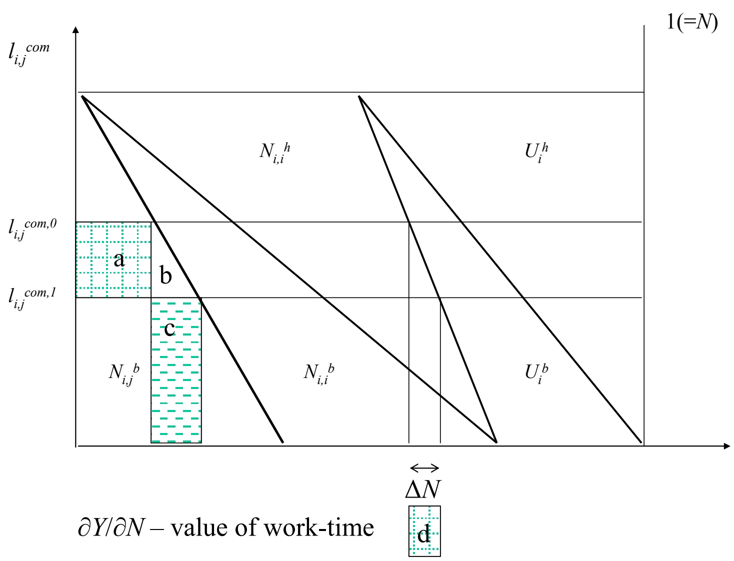

Figure 2b: Job search imperfections

Table 1: Welfare implications of a transport improvement

10% reduction of interregional travel times Annual effects:	DKK
Equivalent variation, EV:	**318.31**
share from commuting times:	46.94
existing commuters	228.26
new commuters	-181.32
additional effects:	271.36
share from consumption goods	414.51
share from working times	-143.14
Net present value CBA (=CS)	
individual VoT	**246.23**
EV relative to CBA:	
individual VoT	**1.293**

APPENDIX A: Calculation of the Consumer's surplus (CS)

In the standard derivation of the *CS* we calculate the *CS* as the area below the demand curve. The demand curve is approximated by a downward sloping straight line thus we end up with the well known rule-of-a half. Letting l^0 and l^1 be the travel time before and after the project, letting *VoT* be the value of time and letting N^0 and N^1 be the number of travellers before and after the project, then this can be written as:

$$CS = \frac{1}{2} \cdot \left(l^0 - l^1\right) \cdot VoT \cdot \left(N^0 + N^1\right) \qquad \text{(a.)}$$

In the derivation above it is assumed that all travellers have the same value of time. In the model used in this paper this is not the case. Here, the travellers have individual values of time. In a better approximation we have to take this into account.

A.1 Calculation of CS in the model (formula (12))

To ease the reading we neglect the indices for residential and workplace region (*i* and *j*) in the following.

Let *l* be a given travel time needed for interregional commuting. Assuming that the workers preference parameter ν is uniformly distributed between 0 and 1, then $\nu^*(l)$ of the workers are potentially willing to commute. All workers with a $\nu \leq \nu^*(l)$ are willing to commute while workers with a $\nu > \nu^*(l)$ are not willing to commute.

For a given worker, with preference parameter ν, the probability of actually being a commuter given the travel time *l* is given by:

$$p(l,\nu) = \begin{cases} \dfrac{\rho(l)}{s + 2\rho(l)} & \nu \le \nu^* \\ 0 & \nu > \nu^* \end{cases} \qquad \text{(b.)}$$

Note that the size of *p(l,v)* defined above does not depend on *v*. Thus, any worker willing to commute has the same probability of actually being a commuter. It is only the marginal point for being a commuter that changes depending on *v*. Let *l*(v)* be the maximal distance that the worker with v is willing to commute. We then have that $\dfrac{\partial l^*(\nu)}{\partial \nu} < 0$.

We now proceed to define the *CS* of travelling. To do this, we consider the two situations for a given travel time *l*:

$$\begin{aligned} &a)\quad l^*(\nu) \ge l \;\Rightarrow\; \nu \le \nu^*(l) \;\Rightarrow\; CS(\nu,l) = \nu \cdot (l^*(\nu) - l) \cdot p(l,\nu) \\ &b)\quad l^*(\nu) < l \;\Rightarrow\; \nu > \nu^*(l) \;\Rightarrow\; CS(\nu,l) = 0 \end{aligned}$$

There is no *CS* of travelling in situation *b)* since no workers with these preferences actually commute. To calculate the total *CS* we therefore only have to consider the situation *a)*.

$$\begin{aligned} CS(l) &= E(CS(\nu,l)) \\ &= \int_0^{\nu^*(l)} \nu \cdot (l^*(\nu) - l) \cdot p(l,\nu) f(\nu) d\nu \end{aligned} \qquad \text{(c.)}$$

The density function *f(v)=1* since *v* is assumed to be uniformly distributed from 0 to 1. We now use that the probability for being a commuter is the same for all workers with *v≤v*(l)* thus:

$$\begin{aligned} CS(l) &= \int_0^{\nu^*(l)} \nu \cdot (l^*(\nu) - l) \cdot p(l,\nu) d\nu \\ &= \int_0^{\nu^*(l)} \nu \cdot (l^*(\nu) - l) \cdot p(l,\nu^*(l)) d\nu \end{aligned} \qquad \text{(d.)}$$

We note that this integral only depends on *l*.

We now proceed by differentiating the *CS(l)* with respect to *l*:

$$\frac{\partial CS(l)}{\partial l} \cong \frac{\partial \nu^*(l)}{\partial l}\nu^*(l)\cdot\left(l^*\left(\nu^*(l)\right)-l\right)\cdot p\left(l,\nu^*(l)\right) - \int_0^{\nu^*(l)} \nu\cdot p\left(l,\nu^*(l)\right)d\nu \qquad \text{(e.)}$$

where we have assumed that $\frac{\partial p\left(l,\nu^*(l)\right)}{\partial l}=0$. With this simplification we neglect the second order effects on employment probabilities of changes in labour market behaviour. This is reasonable since we look at marginal changes in *l*.

Since $l^*(\nu^*(l))=l$, (e.) can be rewritten to:

$$\begin{aligned}\frac{\partial CS(l)}{\partial l} &= -\int_0^{\nu^*(l)} \nu\cdot p\left(l,\nu^*(l)\right)d\nu \\ &= -\frac{1}{2}\left(\nu^*(l)\right)^2\cdot p\left(l,\nu^*(l)\right)\end{aligned} \qquad \text{(f.)}$$

Since $p(l,\nu^*(l))$ is the probability of being a commuter for all workers who are willing to commute and since $\nu^*(l)$ is the proportion of the workers who are willing to commute then the actual number of commuters, $N^b(l)$, for a given travel time are given by:

$$N^b(l)=\nu^*(l)\cdot p\left(l,\nu^*(l)\right) \qquad \text{(g.)}$$

Thus (f.) can be rewritten to:

$$\frac{\partial CS(l)}{\partial l} = -\frac{1}{2}\nu^*(l)\cdot N^b(l) \qquad \text{(h.)}$$

We finally use the approximation that $\frac{\partial CS(l)}{\partial l}$ is linear in *l*. We have tested the linearity by running a series of experiments with small changes in transport costs. Then the demand curves can be drawn and the linear approximation turns out to be reasonable for the relevant small policy changes. Then the change in *CS(l)*, *ΔCS*, as a reduction of travel time from l^0 to l^1 is approximately given by:

$$\begin{aligned} \Delta CS &= \int_{l^0}^{l^1} \frac{\partial CS(l)}{\partial l} dl \\ &= \int_{l^0}^{l^1} -\frac{1}{2}\left(\nu * \cdot N^b\right)(l) dl \\ &\cong \frac{1}{2}\left(l^0 - l^1\right)\left(\frac{\nu *^1}{2} N^{b1} + \frac{\nu *^0}{2} N^{b0}\right) \end{aligned} \qquad \text{(i.)}$$

Since ν*/2 is the average *VoT* for the actual commuters this is the formula (12).