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Congested Interregional Infrastructure, Road Pricing and Regional Labour Markets

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Congested Interregional Infrastructure, Road Pricing and Regional Labour Markets.*

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Abstract

Traffic congestion and the policies to combat it have been studied extensively. However, most studies neglect the labour market impacts of congestion. Many also fail to account for the simultaneity between commuting and migration. This paper models impacts such as unemployment disparities, changes in commuting flows and changes in the flow of migrants by adopting an agent based simulation approach. This approach has the strength that it allows the simultaneous consideration of commuting, migration and labour force participation decisions. The results obtained have important theoretical and policy implications and show how an "optimal" charge may, in fact, be sub-optimal.

Keywords: Congestion, Road pricing, Agent-based approach, Spatial interaction, Infrastructure investment

JEL codes: J61, R12, R23, R41, R48

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1 Introduction

With the global growth in car use, infrastructure is becoming an increasingly scarce commodity. For example, in 2007 Schrank and Lomax (2007) of the Texas Transportation Institute estimated that the annual cost of congestion to the US economy was around 78 billion USD. This presents a significant challenge to policy makers. A number of options are available. Supply can be increased, although this can be costly and may induce fresh demand (Small and Verhoef, 2007 p. 176) or demand can be managed. The introduction of full marginal cost road pricing is one way to reduce demand. The principal is well understood theoretically and has been studied extensively empirically (Winston and Langer, 2006).

The problem of traffic congestion has many dimensions. Policy makers must consider distributional, environmental, efficiency and political factors. All of these aspects have received attention in the literature. However, one area which is usually neglected is the effect on the labour market. Transport infrastructure and policy can have serious effects on flows of commuters, migrants and on the distribution of unemployment. For example, in a study of highway investment Winston and Langer (2006) choose to ignore what they call 'second order effects', by which they mean labour market outcomes. Eliasson (2009) conducts a cost benefit analysis of congestion charging in Sweden but makes no reference to labour market effects. Graham and Glaister (2006) consider the spatial impacts of congestion pricing but also neglect the implications for regional disparities.

There are many reasons for the lack of attention given to labour market impacts of congestion charging. Firstly, there is no clear way to value an even distribution of employment or population. Secondly, it is very difficult to model given that commuting agents can respond to changes in the cost of commuting by continuing to commute, migrating or becoming unemployed. This paper will deal with the problem of modelling the labour market effects of congestion policy by adopting the agent-based computational economics (ACE) approach used by McArthur et al. (2008). This approach allows for the simultaneous consideration of commuting, migration and employment status decisions and offers insight into the way they interact.

The interaction will be analysed by considering a situation where two towns or regions are linked by infrastructure which suffers from congestion. This can be thought of as a single road or a road network which suffers from a bottleneck. It would also correspond to a situation where towns are linked by a bridge or tunnel. The spatial distribution of employment opportunities will be altered. This will potentially cause a change in commuting flows. When capacity on such a resource is limited, a rise in commuting will cause an increase in the level of congestion and with it a rise in the cost of commuting. This generates external costs which are not accounted for by an agent making a decision whether to commute or not. Different policy options will be considered and the effect on the distribution of the population and unemployment will be analysed as well as the aggregate utility level of agents in the model.

The analysis will show that the ability of a congestion charge to improve social welfare depends on labour market conditions and the geographical distribution of employment and workers. Congestion charging attempts to deliver improvements in welfare be discouraging commuters who have a private marginal benefit below the marginal social cost. However, as this paper will show, the welfare implications of this will depend on the subsequent actions of these displaced commuters. In particular it depends on whether they choose to substitute the commuting trip with a migration response. These decisions by agents will also impact upon the pattern of regional disparities.

This interaction between road pricing and spatial labour market outcomes has important policy implications. It is not simply the case that road pricing has an impact on regional disparities but that it actively depends on creating disparities of one kind or another in order to influence the number of commuters. The welfare implications will depend on what kind of disparity is created i.e. a population or unemployment disparity. This also implies that use of road pricing and the aim of closing regional disparities are, at least to some degree, incongruous.

The paper is structured as follows. Details of the ACE approach adopted will be presented in Section 2. Section 3 will outline the experiments conducted using the model and present the results. Section 4 considers the merits of using the proceeds of road pricing to improve infrastructure while Section 5 provides some concluding remarks and policy implications of the results.

2 Model

This paper adopts an agent based computational economics (ACE) approach (Tesfatsion; 2001, 2003). The approach derives macroeconomic results not by working with aggregate relationships but by modelling the behaviour of individual, utility maximising agents. Any phenomena observed in such models has clear microeconomic foundations. This has obvious applications to the current problem. There is no need to define when people will choose to commute, migrate or enter unemployment, all that is needed is to define utility functions for the individuals. Precise details of the simulation model used in this paper are given in McArthur et al. (2008). A very brief outline is given here.

An artificial population of utility maximising agents is generated. Agents in the model are born, they age, marry, give birth, divorce, apply for jobs, retire and die. The conditional probabilities of events such as marriage and giving birth are based on Norwegian statistical tables. Incorporating as much real world information into simulation models as possible is one way to help ensure that the results are representative of the real world. An initial population is created and then the society is allowed to evolve undisturbed over a period of 600 years. The purpose of this is to ensure the population at the end of the period is demographically identical to the Norwegian population and that there are no traces of the initial population. The period could be shorter but as the cost of extending it is low, it may as well be on the upper limit of what is likely to be required to achieve a representative population.

There are two regions (20km apart) which are separated by a natural barrier such as a fjord, river or the sea. This scenario is effectively a dynamic version of Dupuit's Bridge (Dupuit, 1844) as presented in Johansson and Mattsson (1994 pp. 10-15). The advantage of adopting a simulation methodology over an analytical one is that highly complex situations can be analysed. Wages are set exogenously and are equal in both areas. It is possible to allow the wage rates to vary but they are assumed to be exogenous in this paper to simplify the analysis. This represents a situation where wages are rigid and do not respond to labour market conditions. This is not an unreasonable assumption to make in many contexts. The endogenous wage mechanism which is part of the model can be found in McArthur et al. (2008), along with the typical results obtained when using the mechanism. The number of jobs in the system is set to give an unemployment rate of around 5.5%. The precise number varies from year to year depending on the population level. Any adult agent can apply for work and all agents are homogeneous with respect to ability. A simplified situation with homogeneous jobs and workers is considered.

An agent only applies for work if they will experience a net gain in utility. Successful applicants are randomly selected with unfilled vacancies carried over to the next period. No workers are fired in the model with vacancies only becoming available when workers move, retire or die. When the number of basic sector jobs decreases due to exogenous changes or through wage changes, excess workers are shed through natural wastage. This avoids arbitrary decisions about which workers should be fired and adds realistic friction to the model. Unemployed workers receive unemployment insurance. Agents in this model gain utility both from money income and from living in the region in which they were born. Partridge and Rickman (1997) and Bentivogli and Pagano (1999) also model a situation where people have an emotional attachment to a particular region. Individuals are equipped with the following utility function:

$$U_\beta(V, W) = V(e^{-\gamma d})^\beta \tag{1}$$

Here V is a money net of commuting costs. More will be said about the cost of commuting later. It is assumed that agents in the model have a desire to live in the region in which they were born. Reasons for such attachments to areas are outlined by Partridge and Rickman (1997). The second component of the utility function describes this attachment where d is the distance to the individual's place of birth. The parameters (β and γ) quantify the strength of the preferences. The distance deterrence parameter γ is constant for all individuals. The parameter β quantifies how important the individual's location preference is in determining their utility. These parameters are drawn randomly at birth. The location preference parameter, β, is uniformly distributed over the interval (0.5,1). Other types of utility functions and other choices for the distribution of parameters are of course possible.

2.1 The cost of commuting

In McArthur et al. (2008), it was assumed that the cost of commuting was constant. This assumption will be relaxed in this paper and the cost of commuting defined as a function of the number of commuters utilising a road with an assumed capacity limit. This scenario is relevant in the case of the southern part of western Norway where a high number of islands and fjords necessitates the use of tunnels and bridges. In many cases, a single bridge or tunnel provides the only fixed-link between two land masses. When all commuters are forced to use one network connection in this way, the time taken to make such a journey will depend on the number of people making the journey. Because the paper considers the problem of congestion at a macroscopic scale rather than being concerned with the detailed dynamics of the congestion, the model applies to any regions linked by infrastructure which experiences congestion.

There are several ways to model this kind of relationship. An approach which has been used in several studies is the speed-density relationship which relates demand and capacity to travelling time. The form used here is the same as is presented in Noland (1997 p. 383):

$$T_{ij} = d_{ij} * \left[T_0 + T_1 \left(\frac{F_{ij}}{\omega} \right)^{\varepsilon} \right] \tag{2}$$

where T_{ij} is the total time taken to make the journey from i to j, T_0 is the time taken to travel 1 km when there is no congestion, T_1 measures how quickly the journey time rises as the ratio of use to capacity changes, F_{ij} is the flow of commuters from i to j, ω is the designed capacity of the infrastructure and ε is the elasticity of use to capacity. Castillo and Benítez (1995) provide a discussion of the history of the speed-density relationship as well as the various functional forms which have been used. The parameter values used in this paper for T_1 and ε are taken from Noland (1997) and are assumed to be 0.15 and 4 respectively. These estimates are derived from US data although have been found to be consistent with data from other countries. This travel time (T_{ij}) must be converted to a cost in order to be incorporated into the simulation. This is achieved by multiplying Equation 2 by the implied wage per minute. T_0 is assumed to be equal to zero since the purpose of this part of the model is to calculate the cost of congestion, not the cost of the entire journey. T_0 is incorporated into the per km cost of commuting in absence of congestion i.e. 2.5 NOK.

In the next section, one of the policy options considered is the introduction a congestion charge. The cost per km of commuting from i to j in this model is based on Equation 2 and is given by:

$$\Theta = \kappa + \eta \left[T_1 \left(\frac{F_{ij}}{\omega} \right)^{\varepsilon} \right] \tag{3}$$

where η is the implied wage rate per minute and κ is the cost per km of a journey in the absence of congestion. The marginal congestion cost imposed by an additional commuter is given by differentiating Equation 3 with respect to traffic flow and multiplying it by the total number of commuters:

$$F_{ij}\frac{\partial\Theta}{\partial F_{ij}} = F_{ij}T_1\varepsilon\eta\left[\frac{(F_{ij}/\omega)^{(\varepsilon-1)}}{\omega}\right] \tag{4}$$

The total cost of travelling of travelling one kilometre is then obtained by summing 3 and 4 and is presented in Equation 5. This is the congestion charge which will be used in some of the experiments presented in the next section. This gives a total per km cost of commuting of:

$$k = \kappa + \eta T_1(1+\varepsilon)\left(\frac{F_{ij}}{\omega}\right)^{\varepsilon} \tag{5}$$

This is a standard formulation in time-independent commuting models (Lindsey and Verhoef, 2001). This is the road pricing system which will be used as a possible policy option.

Some technical issued have to be dealt with to utilise this formulation. Firstly, when making a decision at time t, an individual does not have information on levels of congestion in that period. This means that they have to form some kind of expectation about how long the journey will take. In this simulation, adaptive expectations are used i.e. people assume that commuting costs in month t will be the same as in month $t-1$. Secondly, the total level of welfare in the system with a congestion charge will be influenced by the fact that the congestion charge is extracted from the system. To avoid this, all congestion charges which are paid are returned to the system. This is achieved by equally dividing the total sum raised through the charge by the economically active population i.e. by adding an amount to the wage rate and unemployment insurance. By leaving the difference between unemployment insurance and the wage rate unaltered, distortions to the system can be minimised.

2.2 Moving costs

In the same way that road capacity is a scarce resource, housing and land suitable for the construction of houses is also scarce. To account for this, the cost of moving from one region to another was specified as a function of the population of the receiving region. This corresponds to a situation where the supply of housing or land is limited. In this way, an agent moving from one region to another causes a rise in the cost of moving to the receiving region and a fall in the cost of moving to the sending region. The cost of moving to a region is calculated as:

$$m_{ij} = TC + ((1 + \frac{P_j}{P})^{\lambda}) - ((1 + \frac{P_i}{P})^{\lambda}) \quad (6)$$

where TC is transaction costs, P_i is the population in Town i, P is the total population of both towns and λ is a parameter modelling the sensitivity of moving costs to asymmetries in the distribution of the population. This elasticity was set equal to 25. This gives modest changes in the cost of moving as the ratio of population changes. The mechanisms is specified such that if the population is exactly equally distributed between the towns then the cost of moving is simply equal to the transaction costs. The congestion component in this mechanism represents a change in land or house prices. As a result, agents must pay the transaction costs and the difference in land prices. If an agent moves from a densely populated town to a smaller town, they will receive the difference as a benefit. This would correspond to a real world situation where someone moves from a high priced city to a low price rural area, for example.

3 Experiments

An economy with two towns located 20 km apart is generated using the model. There is a population of around 33,000 in the model, approximately equally divided between these towns.

3.1 The introduction of a one-time shock

In this set of experiments, an employment shock (-20% jobs in Region 1) is introduced into the system in order to monitor how it responds and what the labour market outcomes are. The experiment will be repeated under three different sets of conditions:

- Unlimited commuting capacity
- Limited capacity where the cost of commuting is determined by the flow in each direction
- Limited capacity where commuters are charged the full marginal cost of their commuting trip

Figure 1 shows the differential between unemployment rates in the towns in each system. A difference of zero indicates that the shock has been spread out equally.

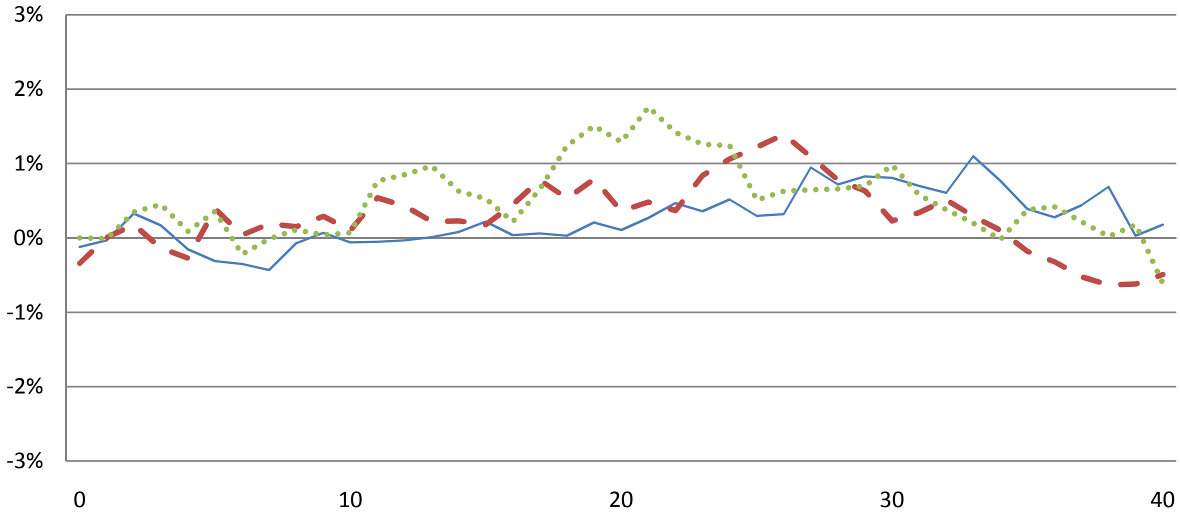

Figure 1: Unemployment differential (T1-T2) with a 20% reduction in employment opportunities in Region 1 in year 10. Scenarios denoted by: Uncongested - solid line, Congested - dashed line and Congestion Charge - dotted line.

Initially, all three systems have an equal distribution of unemployment. This is to be expected since employment opportunities and the population are equally distributed between towns. The employment shock causes a small disparity in all three scenarios. The disparity is largest when a congestion charge is introduced. At it's peak, a disparity of almost 2% is observed in the system with a charge. No significant disparity exists in any of the systems. The lack of a large disparity means that some of the newly unemployed workers in the first town join the workforce of the second town, either through commuting or migration. Because the cost of commuting is different across the three systems, the proportion who commute and migrate is likely to be different. Figure 2 shows the population differential between the towns. This provides information on how many people migrate.

The population begins equally spread out between the two towns, as shown in Figure 2. There is a migration response to the employment shock in all three systems with the size of the response depending on the cost of commuting. The system with the highest cost of commuting, i.e. with a road pricing, responds the most to the shock. This is to be expected since moving becomes more attractive when compared with commuting as its cost rises. In reality, the large shift in population from one town to the other is likely to give rise to indirect and induced effects, exacerbating the disparities between the towns.

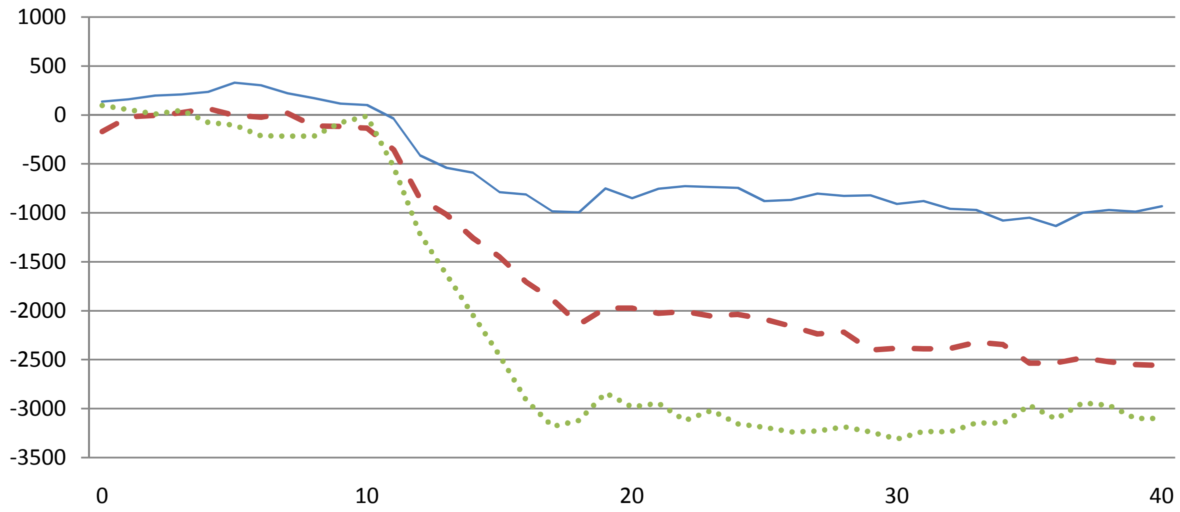

Figure 2: Population differential (T1-T2) with a 20% reduction in employment opportunities in Region 1 in year 10. Scenarios denoted by: Uncongested - solid line, Congested - dashed line and Congestion Charge - dotted line.

This highlights the importance of the simultaneous consideration of migration and commuting. As the cost of commuting rises, an individual's incentives change. Firstly they are less likely to commute. This can result in one of two things happening. Firstly, they may choose to become unemployed if the utility of unemployment is greater than the utility of commuting. They may also choose to substitute their commute with migration. The order of preferences will depend on the characteristics of the individual concerned, wages and the level of unemployment insurance. Failure to consider migration, commuting and employment decisions simultaneously will give biased results. In this model, agents make decisions about whether to migrate or commute based on their expected level of utility from the action. Figure 3 presents the average worker utility.

Unsurprisingly, the highest level of utility is achieved when there is no congestion on the intercity link. The results with respect to congestion charging are a little more surprising. The introduction of a charge appears to approve utility but only marginally; if at all. The reason for such a small difference lies in the relationship between migration and commuting. Consider first the aim of a congestion charge. Market failure results from the fact that from an individuals perspective, they should commute so long as the marginal benefit is greater than the cost they will have to pay to commute i.e. the average cost. From society's perspective, they should commute only if the marginal benefit is equal to the marginal social cost of the commuting. The

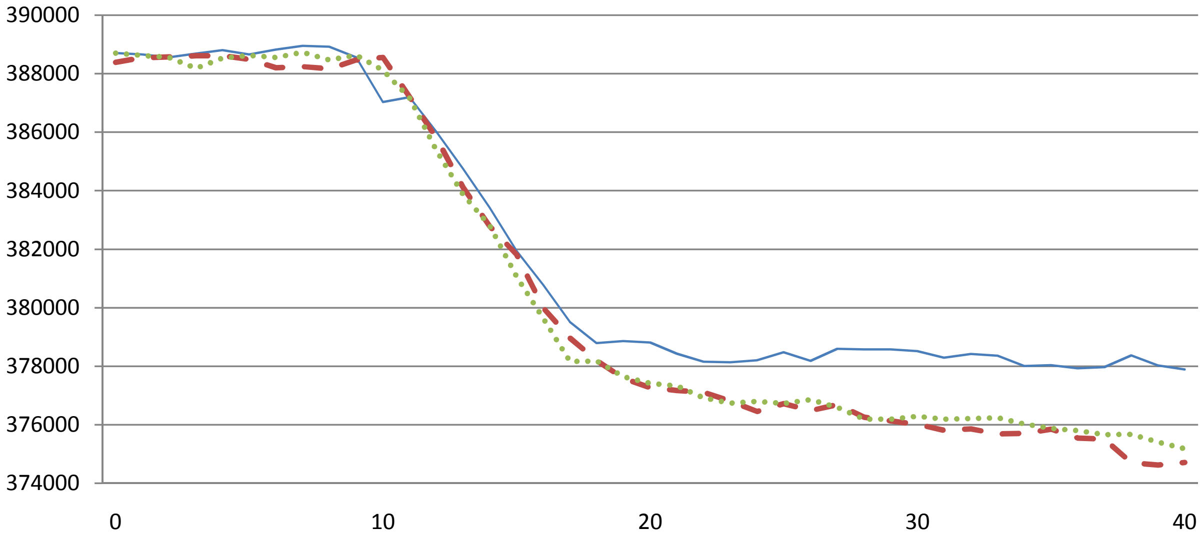

Figure 3: Utility per worker with a 20% reduction in employment opportunities in Region 1 in year 10. Scenarios denoted by: Uncongested - solid line, Congested - dashed line and Congestion Charge - dotted line.

optimal charge aims to align the interests of the individual with the interests of society. In such a case, society will make a saving equal to the cost of commuting in a sub-optimal equilibrium minus the cost of commuting in an optimal equilibrium.

The problem with the reasoning here is that it makes certain assumptions about what happens to the agents who stop commuting due to the introduction of the charge. The optimal response of the agents from a individual and societal perspective is different. Individuals in the model have two components to their preferences: money and location. From a social standpoint, it is best that all workers live in the region in which they were born and work in that region. Subject to a sufficient labour supply in both towns to fill all vacancies, no migration or commuting should take place. In such a case, the average utility is given by evaluating the utility function with average values from the population:

$$U_\beta(V, W) = \text{population} * (u * 300,000 + (1-u)400,000)(e^{-0.005*0})^{0.75} \tag{7}$$

where u is the unemployment rate. If everyone lives in the region in which they were born then the average distance becomes zero and the location component of the utility function can be ignored. A situation with no migration or commuting would not be arrived at without some kind of intervention. This would increase the average distance from the region of birth and would reduce social utility. This is because an agent will migrate so long as the present value of the expected income stream exceeds the cost of living away from their home region (and the one-off pecuniary moving costs). Taking a job in this region will deprive one of the residents of that region a job which will, in turn, cause them to be unemployed or engage in costly moving or commuting. The more people engaged in this activity, the lower the level of social utility.

This is the explanation for the minor difference in utility shown in Figure 3. While there is a social cost saving from the elimination of excessive commuting, additional costs are incurred due to the increased level of migration shown in Figure 2. It is worth noting that these are mainly the psychological costs of moving as the patterns observed persist in the long run. This would not be the case if the observations were only due to transaction costs incurred during the adjustment period. In order to further investigate the interaction between commuting, migration and utility under a congestion charging regime, the distance between the towns was increased from 20 km to 50 km.

3.2 An increase in distance from 20 km to 50 km

This section deals with the same experiment as the previous section but with the distance between the towns increased from 20 to 50 km. The logic remains the same although the real world interpretation of the scenario changes. The two towns can now be thought of either as towns or as two regions. These regions are linked by infrastructure which experiences congestion. This could be because part of the infrastructure is a bridge or tunnel but could simply reflect poor transport links between the regions perhaps due to topographical reasons or due to lack investment in the past. Whatever the reason, it is assumed some kind of bottleneck exists in the system which limits the ability of traffic to flow between the regions.

Increasing the distance between the towns in the model has a number of effects in the model. Commuting becomes more expensive due to the increased distance. The transaction costs of moving are assumed to remain constant but the psychological cost increases. This decreases the attractiveness of both migration and commuting and makes the emergence of regional disparities more likely. The precise results of an increase in distance are difficult to predict. The increased cost of moving will increase the willingness to pay for commuting and vice versa. In addition to this, the increase in psychological costs varies across workers. As a result, it is difficult to say *a priori* what the outcome will be. Figure 4 shows the unemployment disparities generated by the same employment shock used in the last experiment but with a distance of 50 km.

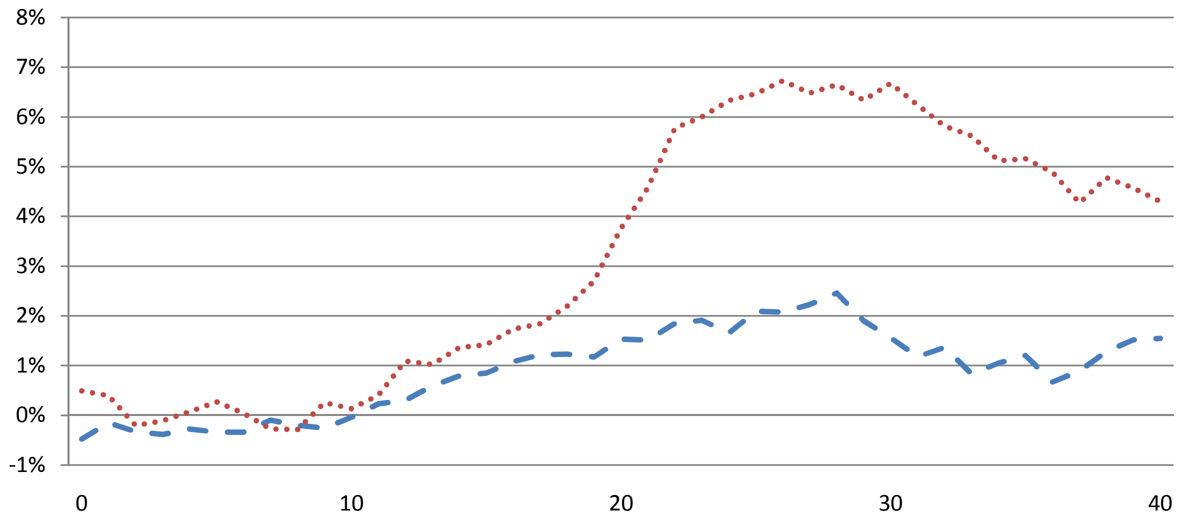

Figure 4: Unemployment differential (T1-T2) with a 20% reduction in employment opportunities in Region 1 in year 10. Scenarios denoted by: Congested - dashed line and Congestion Charge - dotted line.

There are two important points to note about Figure 4. The first is that the increase in the distance between the areas now causes an unemployment disparity to emerge when the employment shock is experienced in Town 1. The second point is that the disparity is much worse when a congestion charge is levied. The utility level per worker is presented in Figure 5.

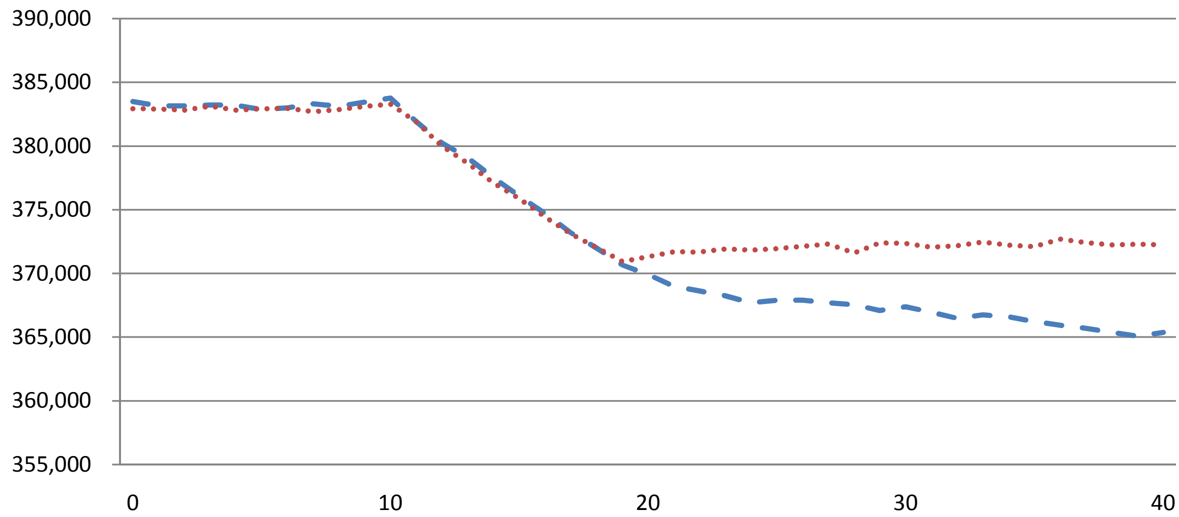

Figure 5: Utility per worker with a 20% reduction in employment opportunities in Region 1 in year 10. Scenarios denoted by: Congested - dashed line and Congestion Charge - dotted line.

In contrast to the results when the distance was 20 km, a distance of 50 km gives a situation where the introduction of a congestion charge significantly improves utility. This result is entirely consistent with the explanation proposed in the previous section. With a distance of 20 km, there was little or no improvement in utility when using a congestion charge. This was a result of the fact that the agents who were discouraged from commuting migrated to the other town instead. This caused them to incur moving costs which lowered the gain which society would have realised had they not have moved. With a distance of 50 km, a far smaller proportion of the agents who were priced out of commuting substituted the commuting with a migration response. Instead, they became unemployment.

In the model, the socially optimum response for displaced commuters is to become unemployed. This is because social utility is maximised when all vacancies are filled, everyone lives in the region in which they were born and all workers work in the region in which they live. A system with 50 km between the towns moves closer to this theoretical ideal than a system with only 20 km. It is important to note that this is not the same as saying a system with a greater distance between the towns experiences a higher level of utility, only that the ordering of utility under different conditions changes with the distance i.e. a congestion charge is optimal when the distance is long but gives reduced benefit as this distance decreases.

These results have important implications. One of the aims of this paper was to investigate the regional labour market implications of congestion and congestion charging. It was stated in the introduction that policy makers have demonstrated a preference for an even spread of unemployment. The two experiments presented in this section give three conclusions. The first is that regional disparities become more likely to emerge or are exacerbated when congestion charging is used as they restrict the spatial integration between the regions. The second is that the optimality of a congestion charge will depend on the response of commuters and particularly the displaced commuters. If they engage in costly moving, then the social benefit of the charge will be reduced and may be negative. Finally, in this model, the congestion charge relies on creating unemployment disparities to effect an improvement in social welfare. This is a somewhat disturbing conclusion given that it means securing welfare improvements thorough congestion charging and an even distribution of unemployment may be incompatible goals.

3.3 Dynamic shocks

One unrealistic aspect of the experiments presented so far is that they model a transition from one equilibrium to another. In such a case, spatial mismatch is a temporary phenomenon restricted almost entirely to the inter-equilibrium period. In the real world context, matching problems are important and occur continuously. This cannot be modelled with a static distribution of jobs. In order to explore outcomes when matching problems exist, the way jobs are allocated between the regions was changed. Rather than an equal number of jobs in each regions, a percentage of the total jobs in the system will move from one region to the other. This will be done so there are enough jobs for 90% of the economically active population. Jobs are divided between the towns according to Equations 8 and 9.

$$J_1 = (0.1 * \sin(0.6 * \text{year} + \pi) + 0.9) * 0.5 * \text{E} \tag{8}$$

$$J_2 = (0.1 * \sin(0.6 * \text{year}) + 0.9) * 0.5 * \text{E} \tag{9}$$

The parameters of this relationship have no interpretation. The mechanisms is a purely mechanical way of moving jobs between the towns in order to simulate job search friction. This relationship keeps the aggregate level of unemployment in the system constant but changes the distribution of the jobs. The sine waves are offset by π so that the peak in employment in Town 1 corresponds exactly with the lowest employment in Town 2. Under this regime, changes in migration and commuting flows are required to match workers with jobs. Unemployment disparities in this system are presented in Figure 6.

The results here are consistent with those presented in Figure 1. The uncongested system experiences the lowest level of unemployment disparities due to its high degree of flexibility. The system with the most expensive commuting, i.e. with a congestion charge, has the highest level of disparities. Although the ordering of the outcomes is the same as in the previous experiment, the magnitude of the differences if greater. The system with congestion charging experiences much higher disparities than either of the other two systems. Because the system is dynamic, there are no persistent disparities. Population adjustment is presented in Figure 7 to show how migration responds to the changes in the distribution of employment opportunities.

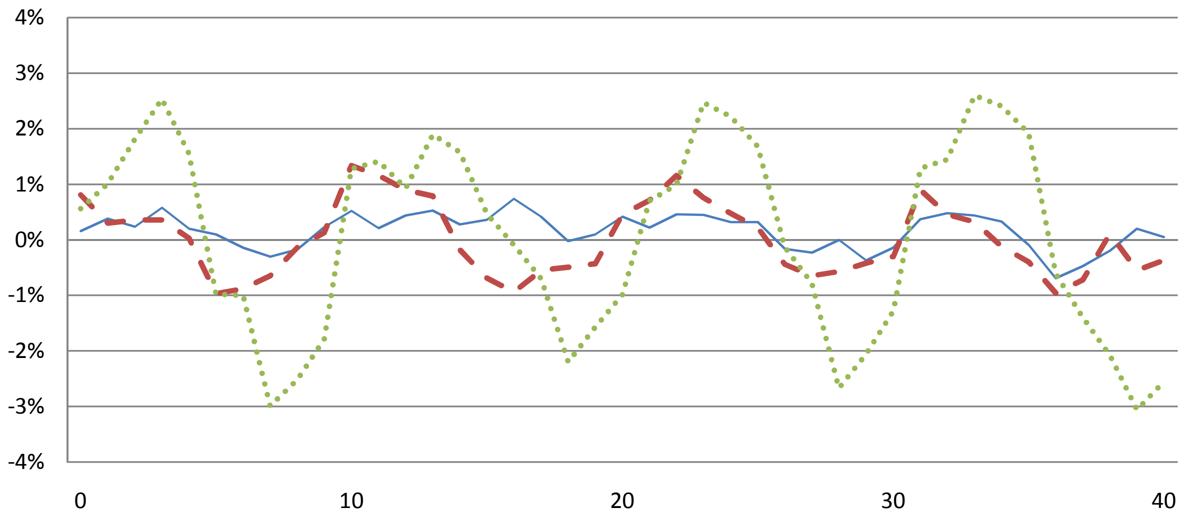

Figure 6: Unemployment differential (T1-T2) with stochastic employment. Scenarios denoted by: Uncongested - solid line, Congested - dashed line and Congestion Charge - dotted line.

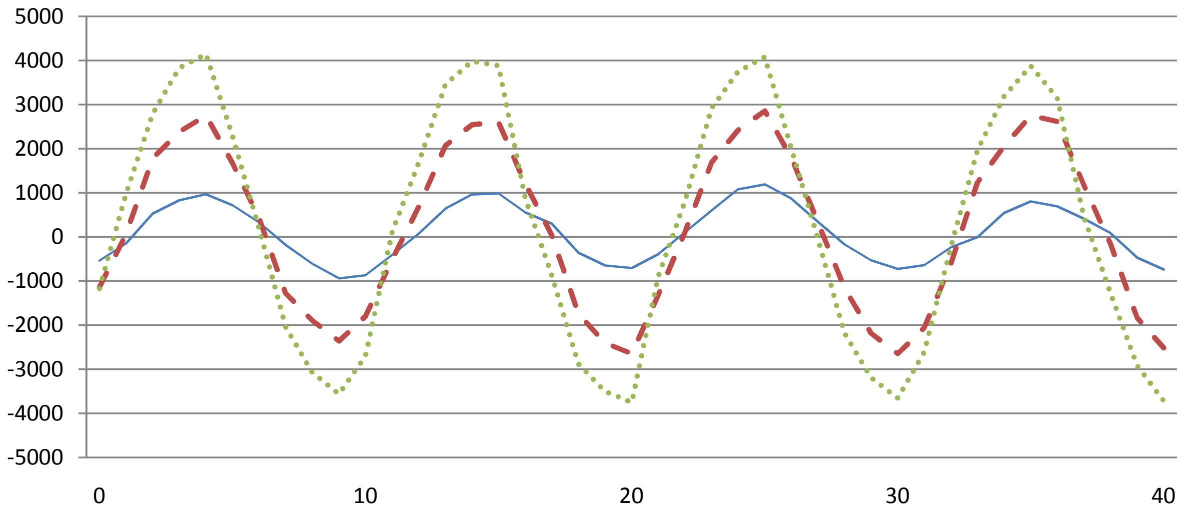

Figure 7: Population differential (T1-T2) with stochastic employment. Scenarios denoted by: Uncongested - solid line, Congested - dashed line and Congestion Charge - dotted line.

Once again, the results are consistent with those in the previous section. Migration is lowest when there is an ample supply of road capacity. As the cost of commuting increases, migration is substituted by many. As a result, it is highest in the case with a congestion charge. Figure 8 shows the average utility per worker for each of the three scenarios.

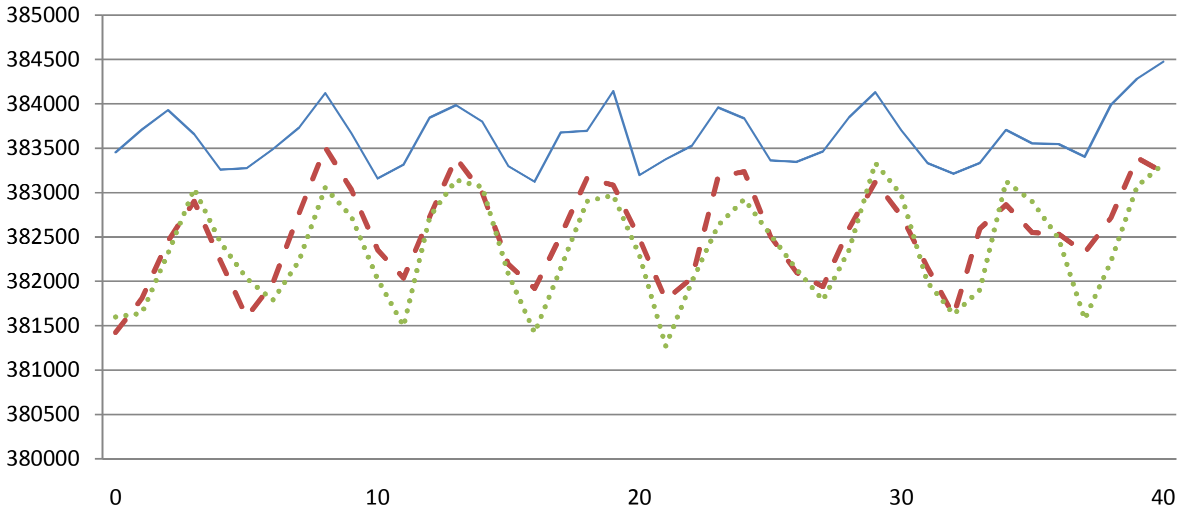

Figure 8: Utility per worker with stochastic employment. Scenarios denoted by: Uncongested - solid line, Congested - dashed line and Congestion Charge - dotted line.

Once again, the system with unlimited capacity provides the highest level of utility for the average worker. There is, however, almost no discernible difference between the congested and congestion charge scenarios. In some years the charge improves the situation while in others it leads to a deterioration. There are two explanations for this. The first is the same explanation as was outlined in the previous section. There are additional problems with the congestion charge in this system. Firstly, because work places are constantly being moved, constant migration is required. This means that transaction costs are continuously being extracted from the system. The second reason is that agents make optimal decisions based on the information available to them which may involve moving instead of commuting. If, however, they were aware that jobs would eventually be moved back to their region, then they may choose to engage in short term commuting or to enter short term unemployment.

In the previous section, an increase in distance led to the congestion charge system outperforming the uncharged system. The next section repeats repeats the dynamic experiments with a greater distance between the towns.

3.4 An increase in distance from 20 km to 50 km

Once again, the distance between the towns is increased and the system re-run. Figure 9 presents a 10 year moving average of the absolute value of the unemployment disparity between the two towns both with and without congestion charging.

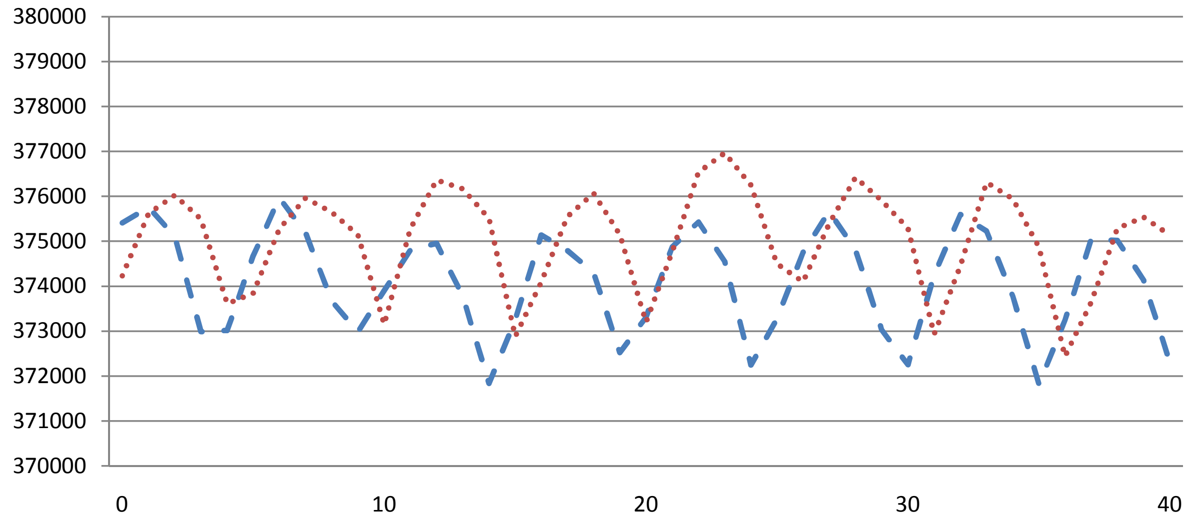

Figure 9: Utility per worker with stochastic employment. Scenarios denoted by: Congested - dashed line and Congestion Charge - dotted line.

The increase in distance has a noticeable effect on the results of introducing a congestion charge. The introduction of a charge now gives a significant improvement in utility, at least on average. Once again, the explanation relates to the actions of the displaced commuters. This congestion charge now generates larger unemployment disparities rather than population disparities. The improvement is not quite as clear as in the static case presented in the previous section. This is caused by the inability of agents to predict the future allocation of jobs. The introduction of the congestion charge encourages additional moving even when there is a distance of 50 km. It would have been better for these workers to engage in seemingly inefficient short-term commuting than to move. In some years, this effect dominates and leads to a fall in utility. However, overall, the majority of displaced commuters become unemployed rather than engaging in costly commuting or migration.

4 Infrastructure Investment

The previous set of experiments showed that a congestion charge did not significantly improve social welfare when there was a short distance between the towns. There is, however, a degree of market failure in this system given that people commute when their private marginal benefit exceeds the marginal social cost. The introduction of a congestion charge was unable to correct this because it encouraged moving which in turn encouraged other agents to engage in moving and commuting. Instead of charging for congestion and then returning the charge to the population, it is possible to retain the charge and then invest it improvements in infrastructure. In order to test the implications of this, the charge collected from the 20 km system was retained until a total of 1 billion NOK was collected. This is a typical kind of sum which would be collected from commuters in Norway through road tolls in order to fund a road expansion. This took a period of 18 years. After time, the capacity restriction was removed and the charge abolished. The average annual utility before, during and after the toll collection period were 382,350, 380,026 and 383,568 respectively.

As can be seen, the introduction and collection of the charge results in a decline in utility. Once the charge is abolished and the infrastructure upgraded, the level of utility increases. The system also experiences a lower level of population and unemployment disparities after the upgrade. In order to evaluate whether the investment is worthwhile, the net present value (NPV) has to be calculated. The utility costs and benefits are calculated on a 'per worker' basis and are compared to the 'do-nothing' scenario of unpriced congestion. The investment involves lower utility for a period of 18 years followed by a potentially infinite period of higher utility. As an assumption, the time horizon is restricted to a 100 year period. One key component in calculating the NPV is the discount rate. The decision regarding whether a given investment is worthwhile can be highly sensitive to the choice of rate. Figure 10 shows the NPV per worker for the investment scenario using different discount rates.

As can be seen, there is little net benefit once the discount rate passes 2%. The rate used by agents in the model is 7%. If this rate is used to evaluate the investment then there is no significant return to the investment. It is not, however, clear which is the best rate to choose. It is also unclear how to deal with the fact that the costs and benefits of a 100 year project will be spread out over multiple generations. It has been argued that the conventional discounting

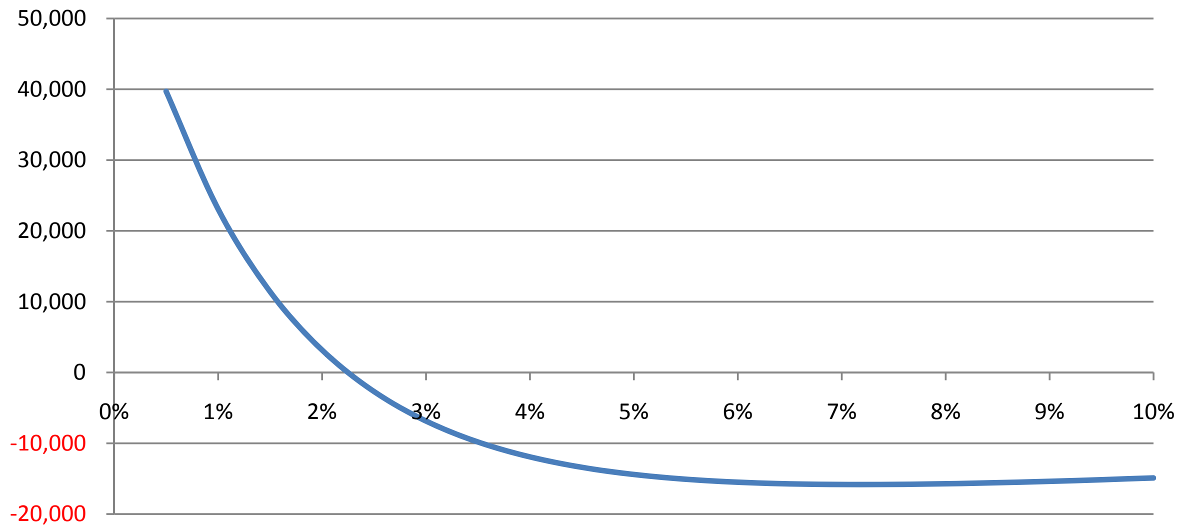

Figure 10: NPV per worker (in terms of utility) for the investment scenario for different discount rates.

methods should not be applied to investments which have intergenerational effects (e.g. Prager and Shertzer, 2006; Sumaila and Walters, 2005; Weitzman, 1998; Henderson and Bateman, 1995; Kula, 1988). Due to lack of agreement on how such investments should be evaluated, it seems sensible to use conventional discounting with a rate of 7% since this is the rate used by agents in the model. At this rate, the experiment shows that, under the assumptions used in the model, it is not possible to improve welfare by using toll charges to invest in infrastructure.

There are, of course, costs and benefits which are not accounted for in this evaluation. For instance, if the population were to increase over time, then the congestion problem would become worse over time. In such a case, the increase in road capacity would be more beneficial than is at first apparent. It could be the case that instead of solving the congestion problem, increasing road capacity induces new commuting demand which leads to new congestion problems (Small and Verhoef, 2007 p. 176). Assumptions also have to be made about economic activity. In the experiment conducted here it is assumed that there are no agglomeration effects and that the aggregate level of employment will be constant. Importantly, infrastructure investment led to lower regional disparities. This may well be beneficial but a discussion of how this should be valued is beyond the scope of this paper. Accounting for all of these potential costs and benefits may well change the decision as to whether investment should be undertaken

5 Conclusion

This paper has considered the labour market impacts of various policies for dealing with congested infrastructure as well as the more traditional efficiency considerations. The first set of experiments considered the transition from one equilibrium situation to another. The results showed that unlimited capacity gave the highest level of utility. Results regarding the use of congesting charging were somewhat surprising. Implementing a charge led to only a modest improvement in the average level of utility. The explanation for observing only a modest improvement was found in the actions of the agents who had been discouraged from commuting and their preferences to live in the region in which they were born. In addition, the use of congestion charging caused a slightly higher level of unemployment disparities and a much larger population differential to emerge. Further investigation where the distance in between the towns in the model was increased showed that a congestion charge improved utility over a congested situation because displaced commuters became unemployed rather than engaging in costly and socially unnecessary migration.

The second set of experiments considered a situation where employment was cyclical and a spatial mismatch between the two areas existed. The aim of these experiments was to try to capture the effect of congestion on matching efficiency. The results in this set of experiments differed from the first set. Once again, uncongested infrastructure provided the highest level of utility. The introduction of a congestion charge had little discernible effect on utility. The failure to realise any benefit was caused by the same factors as in the previous experiment and the fact that transaction costs were repeatedly incurred rather than only being incurred after a one-off shock. Once again, increasing the distance in the system meant that a congestion charge performed significantly better on average than a system with unpriced congestion.

Both experiments demonstrated the importance of infrastructure to the regional adjustment process. Uncongested connections between areas minimised disparities and maximised the utility of agents in the economy. Congested infrastructure lowered utility and increased the level of regional disparities. The introduction of a congestion charge made little difference to utility. It also substantially increased regional disparities. Real world policy makers may be concerned about the social impacts of such disparities even if they do not directly impact on utility in this model. Such a concern suggests that society must have some positive willingness to pay to reduce regional disparities. Placing a monetary value on such benefits is difficult but it is clear that a trade-off exists between the regional distribution of workers and the "efficient" use of infrastructure. It is also clear that there are benefits to be derived from the flexibility offered by adjustments taking place through commuting rather than migration. Interestingly, the experiments in this paper show that the efficient operation of a congestion charge actually relies on creating unemployment disparities.

These results highlight the fact that the implementation of a congestion charge is not a straight forward process. The theory of optimal road pricing makes implicit assumptions about the behaviour and utility functions of agents who stop commuting as the result of the introduction of a charge. In the model used in this paper, this led to the charge performing poorly and even making the situation worse. Attention must be given to other costs and benefits in the system and to distributional impacts of any policies. The analysis here has demonstrated that different policies for dealing with congestion have significantly different impacts on the labour markets. If society is not indifferent to such changes, then they must be taken into account when designing and implementing road pricing systems.

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