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Abstract

This paper develops a numerical optimisation model to study optimal labour and peak-period congestion taxes under different assumptions on the structure of the labour market. We consider both a competitive labour market and various wage bargaining models, in which wages are determined via negotiations between firms and labour unions. All models include commuting and non-commuting transport, and they allow for telecommuting. The models are numerically implemented using Belgian data. We find that wage bargaining models may imply higher or lower congestion tolls on peak period car traffic compared to competitive labour markets, depending on the response of unions to transport issues and the composition of the traffic flow. If unions care about the effect of congestion and congestion tolls on their members' well being, we find the optimal congestion toll for the wage bargaining model to be 15%-20% lower than under competitive labour market conditions. However, if unions do not care about their members' transport problems when negotiating about wages and employment, then the optimal congestion tax is up to 50% higher under bargaining than under competition. We further find that the optimal tax structure results in substantially more telecommuting for all labour market structures considered. Finally, improving the efficiency of telecommuting results in a considerable reduction in optimal congestion tolls.

Key words: congestion taxes, competitive labour markets, wage bargaining, telecommuting
JEL-codes: D62, H21, R41

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1. Introduction

The economic and social consequences of congestion have been widely recognized by economists, and an abundant literature on policies to alleviate congestion has been developed. As many of these policies advocate the introduction of some form of congestion tax, a large number of studies has analyzed first-best and second-best optimal congestion pricing (see, among many others, Keeler and Small (1977), Kraus (1989), Arnott, de Palma and Lindsey (1993), and Verhoef, Nijkamp and Rietveld (1995)). Moreover, as the technology required to implement congestion pricing is now available, a number of cities have actually introduced at least some form of congestion charge (Singapore, Trondheim, Stockholm, London), and many others are seriously considering or preparing its introduction.

Of course, a large fraction of rush hour traffic consists of commuting trips, and policy-makers have expressed some concern about the potential negative employment effects of introducing congestion charges. For many workers, congestion charges raise the cost of commuting to work and hence reduce the net benefits of employment, so that a reduction in labour supply is to be expected. Not surprisingly, a number of recent studies have focused on the close relation between commuting, congestion and the labour market to study both the labour market effects of congestion taxes as well as the implications for optimal congestion charges. First, in a seminal paper, Parry and Bento (2001) assumed competitive labour markets and perfect complementarity between commuting and labour supply. They studied revenue-neutral increases in congestion taxes, whereby the transport tax revenues are recycled through a reduction in the labour tax. They showed that the feedback effects of congestion improve the employment implications of such a transport tax reform, because the reduction in congestion raises the net return to working, making working more attractive relative to leisure. At low levels of the congestion tax, the employment effect of a revenue neutral congestion tax is in fact positive, rather than negative[1]. Second, Van Dender (2003) introduced different trip purposes into the model (commuting and non-commuting) and studied optimal taxes on labour and transport markets, allowing for tax differentiation between commuting trips and other trips. His numerical results show that the labour supply implications of congestion taxes on commuters provide an argument in favour of lower taxes

[1] Relaxing some of the strong assumptions underlying the model may in fact strengthen the employment effects of a congestion tax reform. For example, Guttiérez-i-Puigarnau and Van Ommeren (2009) distinguish two margins of adjustment in the overall labour supply decisions of individuals, viz. the number of days people work per month and the number of hours they work per day. Their empirical results suggest that individuals’ choices of how many days to work per month (and hence commuting demand) and how many hours to work per day respond quite differently to transport and labour tax changes. A transport tax increase may not so much reduce overall labour supply, but rather lead to working more hours per day and fewer days per month.

on commuting than on other trip purposes[2]. Third, Safirova (2002) studied the potential role of telecommuting (the possibility of working at home) in reducing commuting and associated peak-period congestion in a general equilibrium framework[3]. Allowing for agglomeration effects, she finds that the presence of telecommuting may well imply that taxing congestion at marginal external cost reduces, rather than raises, welfare. The intuition is that congestion tolls increase telecommuting demand, which reduces the agglomeration potential of the economy.

The literature surveyed above assumes competitive labour markets. In many European countries, however, the labour market is highly unionized, and wages and employment are the result of negotiations between employer organisations and labour unions. If unions care about the workers they represent and if these workers suffer from congestion or face congestion tolls on their journey-to-work, one expects these issues to come up at the negotiation table, where wage adjustments are discussed with employers. The extent to which changes in congestion or in commuting costs will then be reflected into wage adjustments is likely to depend on the relative bargaining strength of the union, and on the union's preferences with respect to its members' commuting problems. Although there is not yet, to the best of our knowledge, empirical evidence available that documents the effect of congestion and congestion taxes on wage negotiation outcomes on the labour market, anecdotal evidence does suggest that unions do care about commuting costs and congestion[4]. In a recent theoretical paper, therefore, De Borger (2009) reconsiders the problem of peak period congestion taxes in a model of wage bargaining between firms and a labour union[5]. He shows that optimal congestion taxes indeed strongly depend on the union's preferences towards

[2] Such commuting 'subsidies' were also defended on political economy grounds by, among others, Borck and Wrede (2005).

[3] The potential of telecommuting for alleviating congestion has been suggested several decades ago (see, e.g., Nilles (1988), and Lund and Mokhtarian (1994)).

[4] For example, there is press reporting that labour unions in the UK heavily discussed the introduction of the London congestion charging system (www.communitycare.co.uk/articles/2003/01/16/39331/london-congestion-charge). Similarly, although the proposal was ultimately rejected, the introduction of congestion pricing in New York City was strongly debated by unions in the US (see, for example, the New York Times, March 17, 2008). Finally, in Belgium both the Christian democratic and socialist unions (ACV and ABVV, respectively) have organized over the past three years specific conferences on the implications of congestion and congestion pricing.

[5] Analyzing the effects of optimal taxation and tax reform within the framework of wage bargaining models has a long tradition in the literature on environmental taxation (see, among many others, Schneider (1997), Strand (1999), Bayundir-Uppmann and Raith (2003) and Schob (2005)). Unlike congestion, however, environmental externalities do not generate feedback effects on demand, so that the externality itself does not affect negotiated wages and employment. In a recent paper, Van Ommeren and Rietveld (2005) studied commuting in a search model of the labour market where wages are determined through wage bargaining. The model implies that commuting time and commuting costs both affect equilibrium wages, and it explains the 'commuting time paradox' -- i.e., the stability of average commuting times over extended periods of time. It does not include congestion, however, and the paper is not concerned with taxation.

transport issues; more precisely, it depends on the extent to which the union argues for higher wages in response to an increase in congestion and congestion taxes. Suppose, for example, that the union fiercely negotiates for higher wages in response to an increased congestion toll; the paper then finds that it is optimal for the government not to set the congestion toll too high, to limit adverse employment effects. However, if the union does not translate congestion tolls into higher wage demands at the negotiation table, then a higher toll is optimal, because in that case the employment effects of the congestion toll are much more limited. Moreover, the analysis also confirms the desirability of commuting subsidies, provided that part of the peak-period traffic flow comes from drivers that have no employment.

The previous discussion suggests that different assumptions on the working of the labour market (i.e., competitive labour markets or wage bargaining) may well have important implications for optimal labour and peak period congestion taxes. In all cases, the effect of tax changes on employment strongly matters for optimal taxes. However, on competitive labour markets the employment impact of tax changes is determined by individual labour supply responses, whereas under wage bargaining it is mainly driven by the union's preferences and bargaining strength (De Borger (2009)). Hence, one expects numerical differences in optimal taxes depending on the structure of the labour market assumed. What remains unclear, however, is whether such differences are numerically large enough to be worried about; nor is it clear whether congestion tolls will be higher or lower under wage bargaining as compared to competition.

The purpose of this paper is, therefore, to illustrate the impact of making different assumptions on the working of the labour for optimal labour and peak-period congestion tolls, using simple but highly transparent numerical optimisation models. Specifically, we compare optimal labour taxes and congestion tolls derived under competitive labour market conditions and under wage bargaining; in the latter case, we allow for a wide variety of union attitudes towards congestion and congestion tolls. The various models include different trip purposes (commuting and non-commuting), and they allow for telecommuting by assuming exogenous productivity differences between working time on the job and work done at home. The models are calibrated and implemented using Belgian data for the year 2000.

The results of this paper can be summarized as follows. First, wage bargaining models may imply higher or lower congestion tolls on peak period car traffic as compared to competitive labour markets, depending on the importance of transport taxes and congestion in union preferences and on the composition of the peak period traffic flow. Numerical implementation of the models confirms this statement: assuming that union preferences reflect the concerns of their members (in a way made precise below), we find optimal congestion taxes that are 15% lower under wage bargaining than under competitive labour market conditions. However, if at the negotiation table unions put much less emphasis on transport issues, then tolls under bargaining are much higher than under competition. The bargaining model produces optimal congestion taxes that are up to 50% higher than under competitive labour market conditions. Second, in all cases the optimal tax structure results in substantially more telecommuting compared to the current reference situation. As this result is mainly driven by higher congestion tolls, the extent to which telecommuting rises strongly depends on different labour market assumptions and, in the bargaining models, on union preferences. Finally, enhancing the efficiency of telecommuting (in the sense of reducing the productivity difference between working at home and on the job) is found to imply a considerable reduction in optimal congestion tolls under all labour market structures.

The paper contributes to the literature in that (i) it numerically compares the effect of different labour market assumptions on optimal labour and congestion taxes, and (ii) it illustrates the role of telecommuting opportunities for optimal congestion tolls under different labour market structures. Of course, the paper has some obvious limitations. First, we use highly stylized models. However, the main purpose of the paper is to suggest that the way we model the wage formation process may have important implications for the level and structure of optimal congestion tolls. Second, telecommuting is introduced in a very simple way, and we do not incorporate potential agglomeration economies (see, e.g., Arnott (2007), Safirova (2002), Venables (2007)). Third, the model deals with the peak period only and assumes that all transport takes place on a single link, used by both commuting and non-commuting transport. Fourth, there is neither freight nor public transport. Although incorporating these types of travel would substantially enhance the realism of the models, they are not essential for making the points this paper is interested in, viz. the impact of the structure of the labour market for congestion tolls[6].

The structure of this paper is as follows. In Section 2, we briefly discuss optimal taxation under competitive conditions and wage bargaining on the labour market, respectively. A numerical illustration is described in Section 3, focusing on different labour market assumptions and, in the case of the wage bargaining models, emphasizing the role of union preferences. Moreover, the role of increasing the efficiency of telecommuting, in the sense of

[6] In the working paper version of De Borger (2009), public transport was explicitly considered.

reducing the productivity difference between working on the job and working at home, is explored. Finally, conclusions are summarized in Section 4.

2. The analytical models

In this section, we consider two different but highly stylized models of the labour market and look at the implications for optimal congestion taxes. The models are fairly straightforward extensions (for example, to include telecommuting) of models available in the literature. Moreover, to make numerical implementation of the models in the next section as transparent as possible, we keep the models simple. For example, we assume quasi-linear preferences throughout, we assume constant time values and we ignore distributive concerns.

2.1 Commuting, congestion and competitive labour markets

2.1.1 Description of the model

The model we consider assumes that households demand both commuting and non-commuting transport[7]. To facilitate numerical implementation in the next sections, we model consumer preferences by the following specific utility function:

$$u = X + \alpha l + U(T_c, H) + Z(T_{nc}) \tag{1}$$

where $U(.)$ and $Z(.)$ are quasi-concave and continuous. In this expression, X is a composite commodity with price normalized at one, l is leisure time, and T_c and T_{nc} denote commuting and non-commuting car trips, respectively. Finally, H is the number of working days at home, reflecting telecommuting possibilities, see below.

Note that specification (1) is quite restrictive; it is quasi-linear in both general consumption and leisure. However, although it is well known that assuming quasi-linear preferences affects optimal commodity tax rules, there is no reason to believe that they qualitatively affect the comparison between different labour market structures considered in this paper. So the assumptions made clearly limit the generality of the results, but they should not affect the conclusions with respect to the structure of the labour market for optimal

[7] In Belgium an estimated 29% of all person movements in the morning peak in 2000 had a non-commuting nature (see the Mobility Portal of StatBel).

congestion tolls. Finally, note that (1) implies an exogenous value of time, equal to α; this assumption will strongly facilitate the solution of the numerical model below.

The consumer faces a budget and time constraint:

$$(w-t)(T_c+\phi H)+G=X+\tau(T_c+T_{nc}) \tag{2}$$

$$D=l+\left(1+a\right)T_c+H+aT_{nc} \tag{3}$$

The right-hand side of (2) summarizes spending on transport and the general consumption good; the left-hand side gives total labour and non-labour income. Specifically, the net wage per effective labour unit (day) worked is (*w*-*t*), where w is the wage paid and *t* is the labour tax imposed by the government. Total labour supply is expressed in 'effective' working days, i.e., $L_s=T_c+\phi H$, where $\phi\le 1$ reflects the relative efficiency of telecommuting compared to working on the job. The idea is that workers can work at their workplace, but that they also have the option to telecommute. However, telecommuting is assumed to be less productive than working on the job: a day of telecommuting produces less effective labour than a day on the job. It is further assumed that each day of on-the-job work requires a commuting (round-) trip. Further note that all commuting and non-commuting trips are subject to a transport tax τ. Finally, the government provides a lump-sum transfer of G to all households.

Restriction (3) allocates the household's available time *D* to working, leisure and transport. It is taken into account that each day of on the job work requires a congested commuting trip. Congestion is captured by the congestion function *a (.)*; it expresses the time needed per unit of transport (kilometre, trip, etc.) and depends on total road use, i.e., $a=a\left(T_c+T_{nc}\right)$. The congestion technology implies $a'>0, a''>0$.

The first-order conditions of maximizing (1) under constraints (2) and (3) imply commodity demands and labour supply (work on the job as well as telecommuting) as a function of the parameters ($w-t,\tau,a,\phi,G$). Substituting into the utility function yields indirect utility $V(w-t,\tau,a,\phi,G)$ which has, by the envelope theorem, the following properties:

$$\frac{\partial V}{\partial t}=-\left(T_c+\phi H\right)=-L^s;\ \frac{\partial V}{\partial \tau}=-\left(T_c+T_{nc}\right);\ \frac{\partial V}{\partial a}=-\alpha\left(T_c+T_{nc}\right);\ \frac{\partial V}{\partial G}=1;\frac{\partial V}{\partial \phi}=\left(w-t\right)H \tag{4}$$

These properties are entirely standard, except for the utility effect of more efficient telecommuting. Not surprisingly, enhancing telecommuting efficiency (a higher ϕ) raises the highest utility the individual can attain.

Labour demand comes from a competitive production sector; we aggregate, without loss of generality for the problem we are interested in, all production in one competitive firm. It produces a single output with labour as the only input factor. The production function is denoted by $f(L)$, where $f' > 0$ and $f'' < 0$. Output is sold at a fixed world price, here normalized to one, so that the firm's profit is formulated as:

$$\pi = f(L) - wL \tag{5}$$

Profit maximizing behaviour implies that labour demand $L_d(w)$ is the solution of the first-order condition $f'(L) - w = 0$ for L. It follows by the implicit function theorem that $\frac{\partial L_d}{\partial w} = \frac{1}{f''} < 0$.

The effects of exogenous parameters (taxes, homework efficiency) on employment and transport demands are easily derived, see Appendix 1. We find that the labour tax unambiguously reduces employment. Moreover, although the impact of a higher transport tax and of more congestion (a higher *a*) on employment is ambiguous in general, we find that they are highly likely to be negative. Not surprisingly, more efficient homework is plausibly found to reduce commuting demand: although it also affects total labour supply, it reduces the attractiveness of working on the job and hence commuting.

2.1.2 Optimal taxation

The government is assumed to maximize a welfare function that takes account of the well being of the typical individual as well as the firm's profit. Assuming uniform transport taxes on commuting and non-commuting, the optimal tax problem can be formulated as:

$$\max_{t,\tau} \quad V(w-t, \tau, a, \phi, G) + f(L) - wL$$

$$\text{s.t.} \quad tL + \tau(T_c + T_{nc}) = G$$

In Appendix 1 we show that the optimal transport tax for this model satisfies:

$$\tau = MEC + \left(\frac{1-\gamma}{\gamma}\right)\left[\frac{T_{nc}\frac{\partial L}{\partial t} + \phi\left(T_c\frac{\partial H}{\partial t} - H\frac{\partial T_c}{\partial t}\right)}{\frac{\partial T}{\partial \tau}\frac{\partial L}{\partial t} - \left(\frac{\partial T_c}{\partial t}\right)^2}\right] \tag{6}$$

In this expression, γ is the multiplier associated with the government's budget restriction; in the absence of lump-sum taxation $\gamma > 1$. The first term on the right hand side is the marginal external cost, defined as the monetary value of the utility loss due to a small increase in the traffic flow. Given our quasi-linear specification of preferences and using (4), it is given by:

$$MEC = -\frac{\partial V(.)}{\partial a} a' = \alpha(T_c + T_{nc})a'$$

The results reported in Appendix 1 are easily shown to imply that the numerator of (6) is negative and the denominator positive; the tax exceeds marginal external cost.

Interestingly, the numerator of the term between brackets in (6) implies that, as long as the wage elasticities of on the job work and telecommuting differ, the optimal transport tax depends on the worker's division of labour supply between working on the job (and hence commuting) T_c and telecommuting H[8]. Although (6) is obviously not a closed-form solution for the optimal transport tax, the tax rule suggests that more telecommuting in equilibrium reduces the optimal tax, conditional on marginal external cost. Furthermore, more efficient telecommuting affects the tax in two ways: first, conditional on marginal external cost it may raise or reduce the toll, depending on the sensitivities of commuting and telecommuting with respect to the labour tax. Second, however, it also affects transport demand and hence marginal external cost. To see this, differentiate the definition of marginal external cost with respect to ϕ to find:

$$\frac{\partial(MEC)}{\partial \phi} = \alpha\left[a' + (T_c + T_{nc})a''\right]\left(\frac{\partial T_c}{\partial \phi} + \frac{\partial T_{nc}}{\partial \phi}\right)$$

Using the result on the effect of telecommuting efficiency on transport demand (see Appendix 1), it follows that more efficient telecommuting is likely to reduce the optimal congestion tax. Numerical analysis below will confirm this statement.

2.2. Commuting and congestion in a bargaining model of the labour market

In this section we consider optimal labour and congestion taxes, assuming that wages are determined through bargaining between firms and labour unions. Since the model only slightly adapts De Borger (2009), we keep the discussion of the model limited and refer to the original paper for details.[9]

[8] If the elasticities of on the job work and telecommuting with respect to t are equal, (6) implies that the toll exceeds marginal external cost as long as there is non-commuting demand on the road.

[9] Differences include the following: De Borger (2009) looked at right-to-manage bargaining (we assume Nash bargaining in this paper), he assumed time values to be endogenous, and he did not consider telecommuting possibilities. In the working paper version, telecommuting was included. However, the general tax rules are the same, see below.

2.2.1 Description of the model

We assume that unions and firms bargain over wages and employment (i.e. the efficient bargains model, see e.g. Creedy and McDonald (1991)), but that hours of work per employed worker are fixed and not negotiable (assuming otherwise would substantially complicate the analysis, see Hart (2004) for details). Telecommuting is introduced in the same way as in section 2.1 above.

To set up the model, let us normalize the population at 1. A fraction *m* (*m<1*) of the population participates on the labour market, a fraction *(1-m)* does not; this group consists of the retired, discouraged workers, etc. Employment is denoted by L ($L<m$). Let us assume for simplicity that everyone participating on the labour market is unionized (this assumption does not affect the results), hence unionization equals *m*.

Consider the preferences of an employed consumer. He or she cares about a general consumption good C^e, leisure time l^e, non-commuting trips T_{nc}^e, commuting trips (equal to the number of days worked on the job) T_c^e, and the number of days worked at home H^e. The superscript *e* refers to employed consumers. The model assumes that hours per day and the total number of effective working days per employed consumer (i.e., $T_c^e + \phi H^e$) are fixed and normalized to 1 (where, as before, ϕ captures productivity differences between work on the job and telecommuting).[10] The problem facing an employed consumer is then to maximize:

$$u^e = X^e + \alpha^e * l^e + U^e(T_c^e, H^e) + Z^e(T_{nc}^e) \tag{7}$$

subject to

$$\begin{aligned} &(w-t)+G = X^e + \tau\left(T_c^e + T_{nc}^e\right) \\ &D = l^e + (1+a)T_c^e + H^e + aT_{nc}^e \\ &T_c^e + \phi H^e = 1 \end{aligned} \tag{8}$$

where $U^e(.)$ and $Z^e(.)$ are quasi-concave and continuous, and the superscript *e* refers to an employed consumer. The solution yields indirect utility for the employed $V^e\left(w-t,\tau,a,\phi,G\right)$; it has the following properties:

$$\frac{\partial V^e}{\partial t} = -1; \frac{\partial V^e}{\partial \tau} = -\left(T_c^e + T_{nc}^e\right); \frac{\partial V^e}{\partial a} = -\alpha^e\left(T_c^e + T_{nc}^e\right); \frac{\partial V^e}{\partial G} = 1; \frac{\partial V^e}{\partial \phi} = \alpha^e H^e(1+a) \tag{9}$$

[10] Note that the normalizations described above imply that the interpretation of L is similar for the competitive and bargaining models: employment is measured as the number of days worked in the economy considered.

To interpret these effects, remember that effective labour supply per person is fixed in this setting. Note again that telecommuting efficiency raises utility, although for slightly different reasons. Total labour supply per person is fixed, and higher telecommuting efficiency only induces the individual to substitute working at home for on the job work; in doing so, he saves commuting time.

People that are inactive on the labour market (this not only includes the unemployed, but also the retired, discouraged workers, etc.) seek utility in consumption X^u, leisure l^u and transport T^u (which is by implication non-commuting transport). They maximize:

$$u^u = X^u + \alpha^u * l^u + Z^u(T^u) \tag{10}$$

subject to

$$\begin{aligned} X^u + \tau T^u &= G \\ l^u + aT^u &= D \end{aligned} \tag{11}$$

Indirect utility $V^u(\tau, a, G)$ satisfies:

$$\frac{\partial V^u}{\partial \tau} = -T^u; \frac{\partial V^u}{\partial a} = -\alpha^u T^u; \frac{\partial V^u}{\partial G} = 1 \tag{12}$$

Note that total transport demand and marginal external cost are defined slightly differently in the bargaining model, due to the explicit presence of employed people and people that do not work. Total demand is given by:

$$T = L\left(T_c^e + T_{nc}^e\right) + (1-L)T^u .$$

Similarly, marginal external cost is now, using (9) and (12):

$$MEC = -\left(L\frac{\partial V^e}{\partial a}a' + (1-L)\frac{\partial V^u}{\partial a}a' \right) = L\left[\alpha^e (T_c^e + T_{nc}^e)\right]a' + (1-L)\left[\alpha^u T^u\right]a'$$

It captures the monetary value of the utility loss due to an increase in the traffic flow for the employed and people not holding a job.

We assume that union preferences can be captured by a union utility function, which we denote in general as $\Omega(w, L; t, \tau, a)$. Conditional on taxes and congestion, the literature on union behaviour suggests that union preferences positively depend on wages and employment. Moreover, if union preferences at least partially reflect the preferences of their members, one expects union utility to depend negatively on taxes and congestion. In the numerical analysis below we use two specific functional forms that describe very different union attitudes towards transport problems. They imply a different ‘translation’ of transport problems by union leaders at the negotiation table. A first specification assumes that union utility is just the expected utility of its members

$$\Omega = LV^{e} + (1-L)V^{u} \tag{13}$$

In what follows, we refer to this union utility specification as Bargaining Model I.

It is not at all clear, however, that union preferences directly incorporate their members transport concerns. It might be, for example, that the union considers its members' transport problems to be a direct consequence of their decision as to where to live and how to commute to work, and that it does not think of congestion and congestion tolls as very relevant union concerns. Therefore, we also used an alternative – and, admittedly, ad hoc - specification that allows for this idea and that can capture a wide range of union attitudes towards transport problems. Specifically, we formulate the union utility function as

$$\Omega = L^{\theta}\tilde{w} \tag{14}$$

where $\tilde{w} = w - t - \delta\tau - \kappa a$. The parameter θ captures the relative importance of employment relative to wages. The parameters δ and κ can be interpreted as the importance the union places on congestion taxes and congestion, relative to the net wage. Alternatively, κ is the 'value of time' the union implicitly uses when negotiating over wages and employment. Of course, if the union does not attach great importance to neither congestion nor congestion taxes, then both δ and κ will be relatively small. In the remainder of this paper, this second union utility function will be described as Bargaining Model II.

Assuming, as before, that the firm is interested in profit $\pi = f(L) - wL$, the outcome of the bargaining process can be modelled as the solution to the problem of maximizing the weighted geometric mean of the union's utility function and the firm's profit (Solow and McDonald (1982)):

$$\max_{w,L} \Omega^{\mu}\pi^{1-\mu} \tag{15}$$

where μ ($0 < \mu < 1$) captures the relative bargaining power of the union versus the firm. It is well known that wages in the Nash bargaining model as formulated here are a weighted average of marginal and average product of labour (see, e.g., Solow and Mc Donald (1981)). In Appendix 2, we briefly derive the effects of taxes, congestion and telecommuting efficiency on negotiated wages and employment for the two bargaining models considered. The signs of these effects are generally similar to those found under competitive labour markets. It is found that an increase in the labour tax raises negotiated wages and reduces employment; although ambiguous in general, we find that under reasonable assumptions, congestion taxes and congestion lead to higher wages and a decline in employment. Finally, more efficient telecommuting reduces union wage demands and it leads to lower wages and more employment under model I. Not surprisingly, given specification (14), it has no effect in model II.

2.2.2 Optimal taxation

The government again cares about the well being of individuals (both those that work and those that don't) and about the firm's profit. The optimal tax problem is formulated as:

$$\max_{t,\tau} \quad LV^e\left(w-t,\tau,a,\phi,G\right)+\left(1-L\right)V^u\left(\tau,a,G\right)+f(L)-wL$$

s.t. $tL+\tau\left[L(T_c^e+T_{nc}^e)+(1-L)T^u\right]=G$

where L and w are now the outcomes of the negotiations between employers and unions. The optimal tax rules of this problem are derived in De Borger (2009, Appendix C) and Wuyts (2008)[11]. The general rules are easier to interpret if we assume zero income effects of conditional demand. It is shown that in that case the transport tax can be written, independent of the particular bargaining model assumed, as:

$$\tau = MEC-\left\{\frac{(\gamma-1)}{\gamma}\frac{(1-\rho_t)}{\left[S\right]}\right\}\left[T-\frac{L\dfrac{\partial L}{\partial \tau}}{\dfrac{\partial L}{\partial t}}\right]+\left[\frac{\gamma-1}{\gamma}\right]\left\{L\frac{\dfrac{\partial L}{\partial a}}{\dfrac{\partial L}{\partial t}}a'\right\} \tag{16}$$

where

$$S=L\left(\frac{\partial T_c^e}{\partial \tau}+\frac{\partial T_{nc}^e}{\partial \tau}\right)+(1-L)\frac{\partial T_{nc}^u}{\partial \tau}<0 \tag{17}$$

$$\rho_t=L\left(\frac{\partial T_c^e}{\partial a}+\frac{\partial T_{nc}^e}{\partial a}\right)+(1-L)\frac{\partial T^u}{\partial a}<0 \tag{18}$$

The term S is the Slutsky effect, and ρ_t is the feedback effect of congestion on transport demand at given employment. As before, γ is the shadow cost of government funds, the multiplier of the government budget constraint. Note that the employment effects of taxes and congestion refer to their impact on the outcomes of the negotiations.

[11] As noted before, see footnote 8, there are slight differences from the model considered here. However, these do not affect the general optimal transport tax rule given as expression (16) below. They do lead to a slightly different optimal labour tax. The intuition is that right to manage bargaining yields an inefficient wage-employment outcome for which the optimal labour tax corrects; such correction is not needed under Nash bargaining.

Interpretation of the tax rule is easy (for more detailed discussion, see De Borger (2009)). If neither congestion tolls nor congestion have any impact on the outcomes of the wage and employment negotiations, then the tax rule is of the Ramsey type; it then consists of a Pigouvian component equal to marginal external cost plus a revenue-raising Ramsey component that reflects the use of distortionary taxes. However, if higher transport tolls strongly raise negotiated wages and correspondingly reduce employment, then this reduces the optimal transport tax; the lower congestion toll saves employment. Similarly, if congestion itself would strongly reduce negotiated employment, this is a reason for raising the toll (by doing so one reduces congestion and hence raises employment).

The general expression (16) therefore indicates that widely different optimal transport taxes are possible. The optimal tax will highly depend on the specification of union preferences. As shown in Appendix 2, these determine the union's attitude towards transport issues at the negotiation table, and hence the impact of taxes and congestion on wages and employment appearing in (16). Using the two explicit specifications of union preferences suggested before (see (13) and (14)), the tax rules can be worked out to yield, for Model I and Model II, respectively (see Appendix 2):

Bargaining I
$$\tau = MEC + \left(\frac{1-\gamma}{\gamma}\right)\left[\frac{(1-\rho_t)}{(S)} + \alpha^u a'\right]\left((1-L)T^u\right) \tag{19}$$

Bargaining II
$$\tau = MEC + \left\{\frac{(1-\gamma)}{\gamma}\frac{(1-\rho_t)}{[S]}\right\}\left[T - L\delta\right] + \left[\frac{1-\gamma}{\gamma}\right]\left\{MEC - L\kappa a'\right\} \tag{20}$$

First, note the important role of the demand by people that do not work in Bargaining model I. If all peak-period transport demand comes from the employed, then the tax just equals marginal external cost under this specification of union preferences. To the extent that people that do not work contribute to the morning peak the tax rises, but the increase is smaller for higher values of their time. Second, observe the huge variability in optimal tolls implied by bargaining model II, depending on the parameters δ, κ that reflect the union's valuation of toll and congestion increases relative to a labour tax increase. Consistent with our earlier discussion, the tax rises when the union considers congestion to be important (high κ), it declines when the union strongly argues for higher wages in response to higher congestion taxes (high δ).

Finally, note that the tax rules (16), (19) and (20) -- contrary to the case of a competitive labour market, see (6) above -- do neither directly depend on telecommuting nor on telecommuting efficiency ϕ. The reason is that the bargaining model assumed labour supply per person (days per month) to be fixed by the constraint $T^c + \phi H = 1$. This implies that the sensitivity of commuting and telecommuting with respect to labour or transport taxes cannot evolve independently, unlike in the competitive model. However, telecommuting efficiency does affect the level of the optimal toll via congestion. To illustrate this, take a particularly simple case, Bargaining model I, and assume all transport demand comes from the employed. The optimal toll then just reflects marginal external cost, (see (19)); this is defined, given zero demand by people without employment:

$$MEC = L\alpha^e T^e a', \quad T^e = T_c^e + T_{nc}^e$$

Noting that congestion depends on total transport demand, *a=a(T)*, simple differentiation leads to:

$$\frac{\partial MEC}{\partial \phi} = \alpha^e T^e \frac{\partial L}{\partial \phi} a' + \alpha^e L \frac{\partial T^e}{\partial \phi} a' + \left[L\alpha^e T^e \right] a'' \left[L \frac{\partial T^e}{\partial \phi} + T^e \frac{\partial L}{\partial \phi} \right]$$

Rearranging yields:

$$\frac{\partial MEC}{\partial \phi} = \alpha^e \left(a' + a'' L T^e \right) \left[T^e \frac{\partial L}{\partial \phi} + L \frac{\partial T^e}{\partial \phi} \right]$$

The ultimate effect is ambiguous, unlike under competitive labour markets. On the one hand, more efficient telecommuting reduces commuting demand at given employment, reducing congestion; see the final term between the square brackets. On the other hand, better telecommuting conditions also raise employment, and this in turn raises overall transport demand and congestion; this is captured by the first term between square brackets. The numerical analysis below does suggest that former effect dominates the latter, so that optimal tolls are lower when telecommuting becomes more efficient.

2.3 Optimal labour and congestion taxes: comparing different labour market settings

The previous subsections have developed simple models of optimal congestion tolls under different labour market assumptions. Although a general theoretical comparison is difficult, in this subsection we briefly illustrate that important differences are indeed to be expected, using a particularly simple but insightful case. Suppose people that do not work demand no transport at all, so that in all models commuting demand and non-commuting demand comes from the employed (i.e., under bargaining all non commuting and commuting demand comes from the employed). In that case, the transport tax rule for the different models is the following:

Competition $$\tau = MEC + \left(\frac{1-\gamma}{\gamma}\right)\left[\frac{T^{nc}\frac{\partial L^s}{\partial t} + \phi\left(T^c\frac{\partial H}{\partial t} - H\frac{\partial T^c}{\partial t}\right)}{\frac{\partial T}{\partial \tau}\frac{\partial L^s}{\partial t} - \left(\frac{\partial T^c}{\partial t}\right)^2}\right]$$

Bargaining I $$\tau = MEC$$

Bargaining II $$\tau = MEC + \left\{\frac{(1-\gamma)}{\gamma}\frac{(1-\rho_t)}{[S]}\right\}\left[L(T^e - \delta)\right] + \left[\frac{1-\gamma}{\gamma}\right]\left\{MEC - L\kappa a'\right\}$$

The competitive model yields the standard result given before; the first bargaining model yields a toll equal to external cost (in other words, for this specification the Ramsey and labour market terms in (16) cancel out); the second bargaining model can yield widely different taxes depending on union preferences. It should not come as a surprise that one cannot argue in general that taxes will be higher or lower under bargaining as compared to competition. The reason is the huge variability in optimal congestion tolls that is implied by the bargaining model, depending on the attitude of the union at the negotiation table. Do they care about transport taxes and are they willing to push for higher wages whenever transport taxes rise? Do they care about congestion? Do they care about both? This is clearly an empirical matter about which very little information is available in the literature. We therefore turn to a numerical optimisation exercise to see how responsive optimal labour and transport taxes are with respect to labour market assumptions.

3. Numerical illustration

In this section, we try to find out whether the differences are numerically important. A numerical model is developed along the lines of the models of the previous section; they are calibrated and applied using data for the year 2000 in Belgium. In what follows, we first discuss the calibration of the reference situation and describe the data used. We then analyze optimal labour and transport taxes for competitive and various bargaining models of the labour market. Finally, we perform a sensitivity analysis for some relevant parameters of the model.

3.1 Data and calibration of the reference situation

Unless otherwise noted, data were provided by Statbel, a division of the Federal Government Service FOD-Economics. The total Belgian population was slightly over 10.25 million, of which approximately 35% were employed. Although precise estimates of telecommuting are scarce, it is estimated that working at home accounted for some 10% of total employment.

3.1.1 Consumers, producers union preferences

Although some slight modifications are introduced to facilitate the calibration and the comparison between the different models, the numerical model largely follows the structure of the theory. Household utility in the competitive model has been specified as in the theoretical model, see (1):

$$u = C + \alpha * l + U(T_c, H) + Z(T_{nc})$$

Optimizing utility subject to the constraints (2)-(3) yields the demand functions. To facilitate the calibration, flexible specifications were chosen for the functions *U(.)* and *Z(.)*[12] To determine the parameters we combined observed quantity and price information with assumptions on various elasticities. Calibration was based on an uncompensated demand elasticity for commuting and non-commuting traffic with respect to monetary transport costs of, respectively, -0.11 and -0.31; this is consistent with estimates by de Jong and Gunn (2001). The uncompensated net wage elasticity of labour supply was set to 0.2, in line with estimates used by Parry and Bento (2001). In line with Van Dender (2003), the value of time was set at 7.5 euro per hour; this amount to approximately 45% of the wage. It was carefully checked whether the calibrated parameter values satisfied concavity conditions within a wide and reasonable range of values for T_c, H and T_{nc}.

Turning to the bargaining models, the comparison between the models is most transparent in the case where all transport demand (commuting and non-commuting) comes from the employed; we therefore initially focused on this case and fixed utility of households that do not have employment. Their peak-period transport demand is set at zero, so that all commuting and non-commuting comes from people that work (bringing kids to school, shopping, leisure travel on days off, etc.). For the demand structure of the employed a similar procedure was used as for the competitive labour market model. Parameter values were again

[12] For the former, a third power specification was found to be most flexible for calibration purposes; for the latter we used $Z(T_{nc}) = \beta_0 + \beta_1 (T_{nc})^{\beta_2}$.

chosen such that the uncompensated demand elasticities for commuting and non-commuting traffic with respect to monetary costs were, respectively, -0.11 and -0.31.

The parameter capturing the relative inefficiency of telecommuting ϕ was set equal to $0,5$. This may seem very low compared to the scarce empirical literature on the subject. For example, De Graaff and Rietveld (forthcoming) study a sample of Dutch workers that report to at least work some of their time at home. They find that workers that telecommute receive, ceteris paribus, wage compensation that is some 20% lower compared to working on the job. However, their sample only consisted of people reporting at least some teleworking, and a large fraction of the overall working population in Belgium (manual labourers in factories, teachers, etc.) has no option to work at home at all. It is not surprising, therefore, that in order to be consistent with 10% telecommuting in the reference situation, a substantially higher average efficiency difference between telecommuting and on the job work had to be calibrated than the 0.2 suggested by De Graaff-Rietveld.

The production side is similar under all labour market models. The gross wage was set at 16,25€/hr, with a flat labour tax rate of 40 percent (as in Van Dender (2003)), so that the net wage in the reference situation is 9,75€/hr. To facilitate calibration of the production function, a flexible form was again used[13]. To calibrate the parameters we used information provided in Konings and Roodhooft (1997). They produced extensive empirical evidence on the demand for labour in Belgian enterprises, reporting a labour cost elasticity of -0,60. This information was combined with the reference wages and employment levels given before, and with the observed labour share in the Belgian economy to calibrate the production function parameters. Again it was carefully checked whether the resulting expression satisfied all requirements imposed by microeconomic theory.

Finally, we implemented the two union utility functions specified in the theoretical section. The first specification, Model I (see (13)), is just a linear combination of the utilities of the employed and people that do not work. All that is needed are, therefore, the utility function parameters. For the second specification of union preferences, Model II (see (14)), the parameters δ and κ were both set at 0.2. In the numerical analysis reported below, a wide variety of values will be used. Finally, note that, since no reliable estimates for aggregate union power is available for the Belgian economy, we set equal μ to 0.5.

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[13] Specifically, we used $f(L) = \varphi_0 + \varphi_1 \log(L) + \varphi_2 \left(\log(L)\right)^2$

3.1.2 Congestion and transport data

We use transport data that are a mixture of urban and non-urban (i.e., mainly highways) road traffic. In Belgium, approximately 75.1% of all vehicle kilometres were driven on non-urban roads in 2000, and 24.9% on urban roads[14]. To capture congestion, separate aggregate speed-flow relations were determined for urban and non-urban conditions. Analysing a wide range of specifications, Kirwan et al. (2001) suggest that a specific exponential type of aggregate congestion function is the most plausible. We used information in Mayeres et al. (1996) for Brussels to calibrate the aggregate congestion function for urban conditions. It gives the time (in minutes) needed to drive 1 km as a function of the total traffic flow. The congestion function obtained was:

$$60 / s = 1.199376 + 0.000624 \times \exp(14.0203 \times T)$$

where s is the speed (km/hr) and T is the total traffic flow. In a similar way, the non-urban (or highway) congestion function is estimated from data presented in De Borger and Proost (2001). The congestion function is:

$$60 / s = 0.499146 + 0.000853 \times \exp(15.5925 \times T)$$

Both calibrated congestion functions are shown in Figure 1.

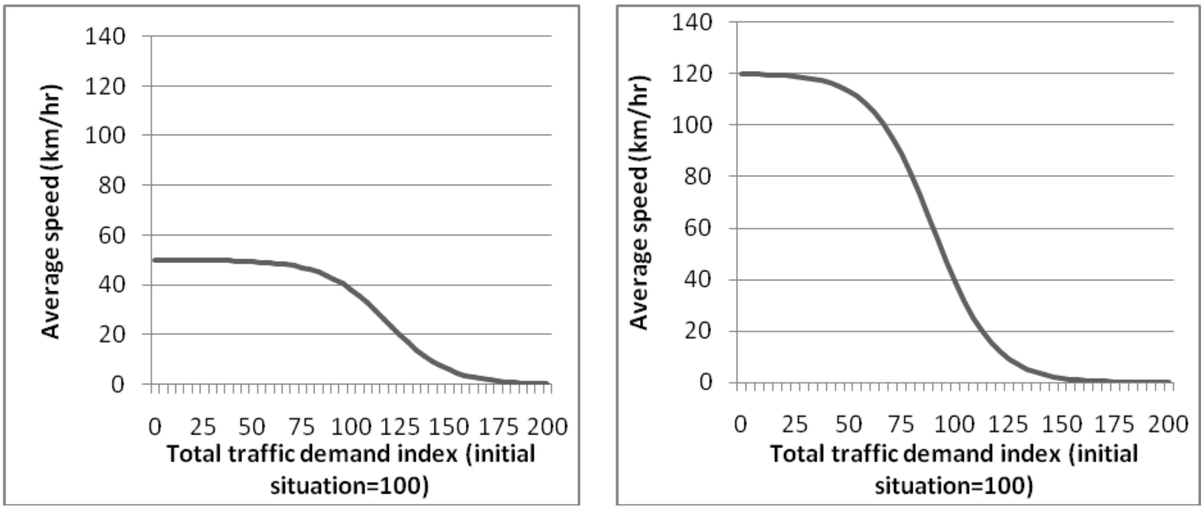

Figure 1: The aggregate congestion function: urban roads (left), non-urban roads (right).

In general, approximately one third (i.e. 33.59 percent) of all passenger movements on a weekday take place in the morning peak between 7 and 9 am. Since no data are available on the extent to which passenger transport on urban and non-urban roads takes place in the

[14] Total vehicle kilometres driven in Belgium in 2000 amounted to 18.027 billion on urban roads and 54.469 billion on non-urban roads.

morning peak, we assume that for both urban and non-urban roads demand corresponds to the mentioned 33.59 percent of overall weekday passenger transport. On non-urban roads, of course, there is also substantial freight transport: some 4.09 billion vehicle kilometres were due to freight transport in 2000. We assumed that the demand for freight transport is uniformly distributed over the day between 6 am and 10 pm (i.e. no peak moments occur) and that a truck is, in terms of its contribution to congestion, equivalent to two passenger cars. Furthermore, we make the (admittedly strong) assumption that the demand for freight transport remains constant throughout our analysis.

The StatBel data imply that, in the morning peak, 71.11 percent of all person movements has a commuting nature. We therefore set the initial commuting and non-commuting percentage of passengers on the road (both urban and non-urban) to respectively 71.11 percent and 28.89 percent. Furthermore, the average one-way commuting trip was assumed to be 20 km.

The cost structure of car transportation is kept simple; it is based on recent key data from the Belgian Automobile Association (VAB). They reported for 2000 that a medium sized car that drives 16.000 km/year implies an average cost of 0,363 €/km, which includes amortization, insurance, vehicle tax, fuel costs, etc. Some 20% of the observed cost (viz., 0,062€/km) is due to fuel taxes. In the numerical illustration, taxes on fuel are considered as the initial variable tax on car transportation.

3.2 Numerical results

In this section, we present results for a number of different numerical optimisation exercises. A large number of simulation exercises is possible, and one cannot expect the results to give more than a flavour for the differences that might result for different assumptions on the labour market. To keep the analysis as transparent as possible, we focus on just a few examples that lead to a number of intuitive insights and that clearly illustrate the differences between the models. A first numerical exercise focuses on differences between competition and bargaining for the specific case where all peak period transport demand comes from people that work. This may not be unrealistic in at least some cities: although there are non-commuting trips (especially when allowing for trip chaining, treating each part of the trip as a separate trip), many of such trips come from people that do hold a job. A second application illustrates the crucial role of union preferences by comparing different bargaining models, again focusing on a few highly transparent cases. A third numerical example presents some results on the effect of telecommuting efficiency for optimal taxes and congestion levels.

3.3.1 Optimal congestion tolls under competitive and non-competitive labour markets

In this subsection we focus on a comparison of the competitive labour market model with wage bargaining model I, which assumed that union utility reflected the preferences of its members. We numerically optimized, starting from a given reference situation based on the initial taxes, labour and congestion taxes; we further calculated the implications of optimal government policies for employment, wages, traffic flows, the degree of telecommuting, etc.

A number of relevant results are summarized in Table 1. Data for the reference equilibrium are reported in column 2. Consistent with many previous studies (see De Borger and Proost (2001)), due to very high congestion on the Belgian road network in the peak period, the transport tax is far below the marginal external cost (respectively 0.062 euro compared to 0.767 euro per kilometre). The other columns report optimal tolls for a competitive labour market setting (column 3) and for bargaining Model I (column 4).

Consistent with the theoretical work of the previous section (see section 2.3), the wage bargaining model yields – under the assumptions made -- lower congestion taxes (and correspondingly higher labour taxes) as compared to the competitive model. Optimal congestion taxes in the bargaining model amount to 0.348 euro/km; the corresponding tax in the competitive model is 0,394 euro/km[15]. In line with theory, since all demand comes from people holding a job, congestion taxes in the bargaining setting are – in the optimum – equal to the marginal external cost of congestion. Congestion taxes under competition exceed (by some 4 eurocents per kilometre) the marginal external cost. Traffic levels decline most, relative to the reference situation, under competitive labour market conditions.

[15] We also numerically implemented the model under the assumption of potential tax differentiation between commuting and non-commuting transport. The results confirmed the optimality of commuting subsidies under specific conditions, see Van Dender (2003) and De Borger (2009) for details. Moreover, telecommuting is generally stimulated more under uniform than under differentiated taxes, precisely because of the commuting subsidies in the latter case.

Table 1: Optimal tax results: Comparing different labour market models

	Initial situation	Competitive labour market model	Bargaining model I
Employment	3 510 088	3 541 867	3 545 048
Wage	130	128.059	127.972
Labour tax	52	35.964	38.184
Transport tax	0.062	0.394	0.348
MEC	0.767	0.357	0.348
Total traffic	187.054	169 365	168 780
Commuting traffic	133.014	125.370	123.022
(% total traffic)	(71.11%)	(74.02%)	(72.89%)
Non-commuting traffic	54.040	43.996	45.758
(% total traffic)	(28.89%)	(25.98%)	(27.11%)
Average speed	38.798	53.442	53.910
Total days of homework	369 483	815 246	838 989

Employment	Number of full time jobs
Wage	€/day
Labour tax	€/day
Commuting transport tax	€/km
MEC	€/km
Total traffic	million vehicle kilometres
Commuting traffic	million vehicle kilometres (% share of total traffic between brackets)
Non-commuting traffic	million vehicle kilometres (% share of total traffic between brackets)
Average speed	Km/hr
Total days of homework	Number of (8 hour) days that are worked at home

Due to the high current reference labour tax (Belgium is well known for quite high taxes on labour) and optimal charging for the congestion externality, optimal labour taxes are substantially lower than in the reference situation. For both models, the implementation of optimal labour and congestion taxes implies that wages decline and employment (employment is here expressed as total fulltime jobs) rises. In other words, the effect of lower optimal labour taxes on wages dominates the opposite wage effects due to higher congestion tolls. We also see that, independent of the labour market structure assumed, at the optimum telecommuting (homework) is much higher than in the reference equilibrium. In fact, working at home rises by more than 100%. Substantially higher congestion taxes and lower taxes on labour have a double effect: lower labour taxes stimulate employment in general, and the dramatic increase in congestion taxes further shifts employment from working on the job towards telecommuting.

Finally, note that both commuting and non-commuting traffic decline considerably. As a consequence, and as expected, congestion and *MEC* go down. The nonlinearity of the congestion function in fact implies that a reduction in total traffic demand of less than 10% results in a substantial increase in average speeds; they go up by almost 40%.

3.3.2 Optimal congestion tolls under wage bargaining: the role of union preferences

In this subsection, we zoom in on the crucial role of union preferences for optimal taxes in the wage bargaining models. As argued before, the assumptions implicit in bargaining Model I may not be realistic. There it was assumed that the union's preferences on transport issues are just a direct translation of the preferences of their members, and that the union behave accordingly in its negotiations with firms. However, it is probably realistic to assume that unions do not care about congestion and congestion taxes to the same extent as their members do. For example, they may argue that part of the congestion problem is due to the government's tax policies and households' decisions as to where to live.

To illustrate the importance of union preferences we consider in Table 2 three different specifications of union preferences: those implied by bargaining Model I (the column for Model I in Table 2 just reproduces the relevant column of Table 1, see the previous subsection), and two examples of the second utility specification, Model II. In one case, we assume that the union's behavior during the wage and employment negotiations is consistent with $\delta = 1; \quad \kappa = 0.2$. In other words, at the negotiation table the union treats a higher congestion toll just the same as a higher labour taxes, but it cares much less for congestion itself. In a second case, we assume that the union does not take congestion and transport taxes into account at all. The final column of Table 2 therefore assumes $\delta = \kappa = 0$.

The results are easily described. First, look at the case where the union cares a lot about congestion tolls (the case $\delta = 1; \quad \kappa = 0.2$). In that case it will strongly argue for higher wages after an increase in congestion tolls occurs, and employment will decline. It is therefore in the government's interest to set the tax on peak-period transport quite low; this reduces wage pressures of the unions and saves employment. We find that the optimal tax is below marginal external congestion cost; it amounts to 0.244 euro compared to *MEC*=0.434 euro. The labour tax is at the same time higher than under bargaining Model I.

Table 2: Comparing different bargaining models

	Initial situation	Union model I	Union model II ($\delta = 1; \quad \kappa = 0.2$: high weight transport tax, small weight congestion)	Union model II ($\delta = \kappa = 0$: transport irrelevant to union)
Employment	3 510 088	3 545 048	3 491 313	4 133 568
Wage (€/day)	130	127.972	130.900	101.837
Labour tax (€/day)	52	38.184	43.436	21.112
Transport tax (€/km)	0.062	0.348	0.244	0.637
MEC (€/km)	0.767	0.348	0.434	0.333
Total traffic (million veh. Km)	187.054	168.780	173.895	167.731
Commuting traffic (million veh. km)	133.014	123.022	125.845	122.126
Non-commuting traffic (million veh. km)	54.040	45.758	48.042	45.605
Average speed (km/hr)	38.798	53.910	49.788	54.745
Total days of homework	369 483	938 989	698 876	2 160 851

If the union does not care about its members' transport problems at all ($\delta = \kappa = 0$), then optimal congestion taxes are considerably higher (and the labour tax correspondingly lower) than in all previous cases considered (both in Table 1 and Table 2). The optimal congestion tax now amounts to 0.63 euro/km and it substantially exceeds marginal congestion cost. The theory suggested that a low weight of congestion tolls in union preferences would raise the optimal toll; a low weight of congestion itself would reduce the toll. The results suggest that the former effect is much more important.

Note that union preferences have rather strong side effects on the extent of telecommuting at the optimal taxes; these differences, of course, are the direct consequence of large differences in congestion tolls. For example, there is a rather dramatic increase in telecommuting if the union does not care about transport issues at all. The intuition is easily understood within the context of our model. The union's behaviour results in an extremely high congestion toll. Our model assumes that worker productivity, and hence wage per hour, is lower when people work at home. However, for a given productivity difference firms do not impose any further restrictions on their workers' choices. Not surprisingly, then, that the high congestion toll induces large responses in favour of working more at home. In reality, however, one might expect (not captured by the model) that the productivity difference depends on the type of job and, more generally, that it depends on the degree of telecommuting already attained in the economy. So, although our results definitely point the right direction for the various effects of telecommuting, their absolute value might be overstated due to the assumption of constant ϕ, independent of telecommuting levels.

3.3.3 The relative efficiency of telecommuting and congestion

We finally consider the effect of changing the efficiency of telecommuting. Technological improvements, especially in a knowledge-based society (in which manual labour is losing some of its significance) may over time reduce the productivity difference between on the job work and telecommuting. We hence perform a simple sensitivity analysis to find out how relatively modest changes in the efficiency of telecommuting would affect optimal congestion policies. We limit the discussion to the competitive model with uniform transport taxes; similar results hold for the other models. In Table 3 we report the results of increasing the efficiency of homework ϕ from 0.50 to 0.55. Figure 2 illustrates the relation between telecommuting efficiency and optimal congestion taxes for a broader range of values of ϕ.

In considering Table 3, first note that the change implemented is not trivial at all, remembering that for a large fraction of jobs telecommuting is simply not an option at all (production workers, etc.). The main result of the exercise is that it illustrates that more efficient telecommuting indeed reduces optimal congestion taxes. For $\phi = 0.5$ we have an optimal toll of 0.394 €/km; if efficiency is increased to 55%, the optimal congestion tax declines to 0.353 €/km, see the last column of Table 3. This reduction in congestion tax is expected: working at home becomes more attractive, this makes peak period traffic levels go down and congestion declines; a lower tax is needed to correct for external congestion costs as a consequence. Figure 2 suggests that the decline in the optimal congestion tax levels off somewhat at higher values of telecommuting efficiency.

Table 3: Increasing the efficiency of homework

	Reference situation	Optimal taxes ($\phi = 0.5$)	Optimal taxes ($\phi = 0.55$)
Employment	3 510 088	3 541 867	3 579 442
Wage (€/day)	130	128.059	125.818
Labour tax (€/day)	52	35.964	37.983
Transport tax (€/km)	0.062	0.394	0.353
MEC (€/km)	0.767	0.357	0.290
Total traffic (million veh. km)	187.054	169 365	164.555
Commuting traffic (million veh. km)	133.014	125.370	119.168
Non-commuting traffic (million veh. km)	54.040	43.996	45.387
Average speed (km/hr)	38.798	53.442	57.228
Total days of homework	369 483	815 246	1 091 358

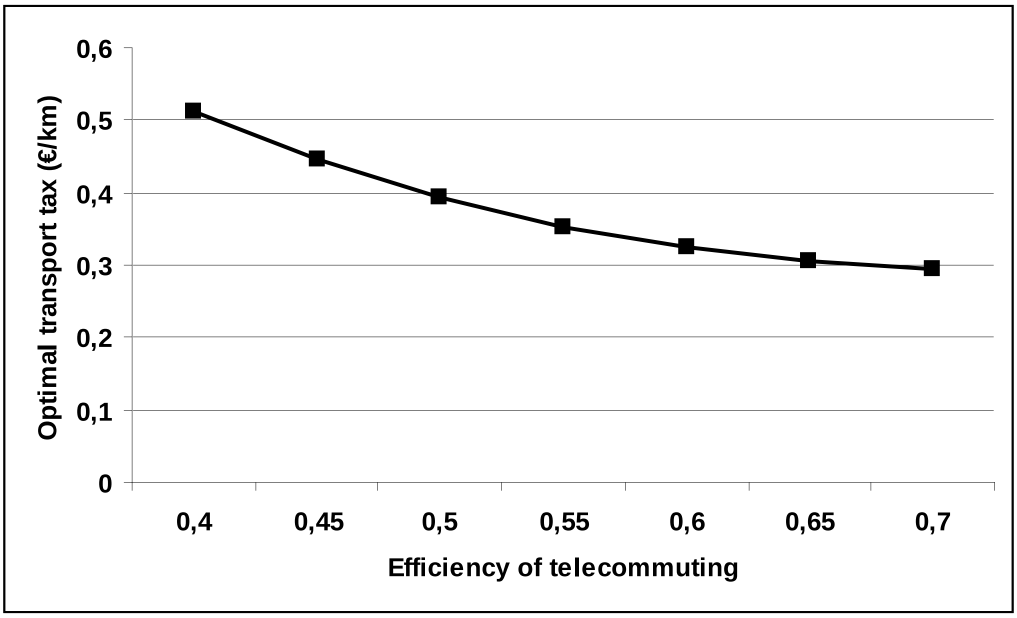

Figure 2: The effect of telecommuting efficiency on optimal transport taxes

4. Conclusion

In this paper we provided a theoretical and numerical comparison of different models of optimal congestion taxes; the models made different assumptions on the structure of the labour market and the wage formation process. Both competitive labour markets and various wage bargaining models were used. We first showed that major differences in labour and congestion taxes may result, due to the different responses of wages and employment to tax and congestion changes, and pointed out the role of union preferences. Numerical implementation of the models using Belgian data confirms these predictions: assuming union preferences reflect the concerns of their members, we find optimal congestion taxes that are 15% lower under wage bargaining than under competitive labour market conditions. However, if at the negotiation table unions put much less emphasis on transport issues, then tolls under bargaining are much higher than under competition. The bargaining model produces optimal congestion taxes that are up to 50% higher than the model assuming competitive labour market conditions. We further find that enhancing the efficiency of telecommuting results in considerably lower optimal congestion tolls under all labour market settings. Vice versa, at given telecommuting efficiency, the optimal tax structure results in substantially more telecommuting compared to the current reference situation.

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Appendix 1: Congestion and optimal taxes on competitive labour markets

In this appendix, we first look at the effects of taxes and congestion on households' labour supply, given a competitive labour market setting. We then derive optimal labour and transport taxes.

The effect of exogenous parameters on labour market outcomes

The first-order conditions of the household's optimization problem (where (2) and (3) are substituted in (1)) are given by:

$$w-t-\tau-\alpha*(1+a)+U_{T_c}=0$$
$$\left(w-t\right)\phi-\alpha+U_H=0$$
$$-\tau-\alpha a+Z_{T_{nc}}=0$$

Differentiate this system, write the result in matrix notation and solve by Cramer's rule to find the partial effects of t, τ, a and ϕ on T_c, H and T_{nc}. This yields, for example, the following effects of a labor tax increase:

$$\begin{aligned}
&\frac{\partial T_c}{\partial t}=\frac{Z_{T_{nc},T_{nc}}}{\left|\Delta\right|}\left[U_{H,H}-\phi U_{T_c,H}\right]\\
&\frac{\partial H}{\partial t}=\frac{Z_{T_{nc},T_{nc}}}{\left|\Delta\right|}\left[\phi U_{T_c,T_c}-U_{T_c,H}\right]\\
&\frac{\partial T_{nc}}{\partial t}=0\\
&\frac{\partial L^s}{\partial t}=\frac{\partial\left(T_c+\phi H\right)}{\partial t}=\frac{Z_{T_{nc},T_{nc}}}{\left|\Delta\right|}\left[U_{H,H}+\phi^2U_{T_c,T_c}-2\phi U_{T_c,H}\right]
\end{aligned}\qquad\text{(A1.1)}$$

where, using the definition $L^s=T_c+\phi H$, the final expression is the effect on labour supply. Note that Δ is the Hessian matrix:

$$\Delta=\begin{bmatrix}U_{T_c,T_c} & U_{T_c,H} & 0\\ U_{T_c,H} & U_{H,H} & 0\\ 0 & 0 & Z_{T_{nc},T_{nc}}\end{bmatrix}$$

where $|\Delta|<0$ by the second order conditions, assuming concavity of the objective function.

Simple algebra shows that the second-order conditions imply a negative effect of the labor tax on labor supply. The labor tax effects on commuting and homework demand are ambiguous in general (depending on the sign and magnitude of $U_{T_c,H}$). Plausibly, one expects both effects to be negative as well. Given the quasi-linear specification of preferences the labor tax has no effect on non-commuting demand.

Similarly, we find that a transport tax increase implies the following effects:

$$\frac{\partial T_c}{\partial \tau} = \frac{U_{H,H} Z_{T_{nc},T_{nc}}}{|\Delta|}$$
$$\frac{\partial H}{\partial \tau} = -\frac{U_{T_c,H} Z_{T_{nc},T_{nc}}}{|\Delta|}$$
$$\frac{\partial T_{nc}}{\partial \tau} = \frac{1}{Z_{T_{nc},T_{nc}}} \qquad \text{(A1.2)}$$
$$\frac{\partial L^s}{\partial \tau} = \frac{\partial \left(T_c + \phi H \right)}{\partial \tau} = \frac{Z_{T_{nc},T_{nc}}}{|\Delta|} \left[U_{H,H} - \phi U_{T_c,H} \right]$$

Transport taxes unambiguously reduce commuting demand. Provided $U_{T_c,H}<0$, they raise homework, a plausible finding. Further note, for later reference, that quasi-linear preferences imply:

$$\partial L_s / \partial \tau = \partial T_c / \partial t \qquad \text{(A1.3)}$$

Congestion has the following effects on transport and labour market outcomes:

$$\frac{\partial T_c}{\partial a} = \alpha \frac{U_{H,H} Z_{T_{nc},T_{nc}}}{|\Delta|}$$
$$\frac{\partial H}{\partial a} = -\alpha \frac{U_{T_c,H} Z_{T_{nc},T_{nc}}}{|\Delta|}$$
$$\frac{\partial T_{nc}}{\partial a} = \alpha \frac{1}{Z_{T_{nc},T_{nc}}} \qquad \text{(A1.4)}$$
$$\frac{\partial L^s}{\partial a} = \frac{\partial \left(T_c + \phi H \right)}{\partial a} = \alpha \frac{Z_{T_{nc},T_{nc}}}{|\Delta|} \left[U_{H,H} - \phi U_{T_c,H} \right]$$

Interpretation is the same as for the transport tax. Finally, more efficient homework implies:

$$\frac{\partial T_c}{\partial \phi} = \frac{\left(w - t \right) U_{T_c,H} Z_{T_{nc},T_{nc}}}{|\Delta|}$$
$$\frac{\partial H}{\partial \phi} = -\frac{\left(w - t \right) U_{T_c,T_c} Z_{T_{nc},T_{nc}}}{|\Delta|} \qquad \text{(A1.5)}$$
$$\frac{\partial T_{nc}}{\partial \phi} = 0$$
$$\frac{\partial L^s}{\partial \phi} = \frac{\partial \left(T_c + \phi H \right)}{\partial \phi} = \frac{\left(w - t \right) Z_{T_{nc},T_{nc}}}{|\Delta|} \left[U_{T_c,H} - \phi U_{T_c,T_c} \right]$$

A higher efficiency of telecommuting raises demand for telecommuting. The effect on commuting demand and on labour supply is ambiguous in general. Note from (A1.4)-(A1.2), however, that if the congestion tax stimulates homework then more efficient homework reduces commuting demand.

Given the labour supply effects of taxes, the impact of taxes and congestion changes on the resulting equilibrium wage and employment outcomes easily follow. For example, the effects of a higher labour tax are, using the market equilibrium condition and the implicit function theorem, are given by:

$$\frac{\partial w}{\partial t} = -\frac{\frac{\partial L_s}{\partial t}}{\frac{\partial L_s}{\partial w} - \frac{\partial L_d}{\partial w}}; \quad \frac{\partial L}{\partial t} = \frac{1}{f''}\frac{\partial w}{\partial t}$$

Effects of transport taxes, congestion and telecommuting efficiency on wages and employment are determined in an analogous fashion. Note that this also implies that the employment effects of tolls and congestion relative to the effects of a labour tax increase just depends on the relative labour supply effects.

<u>Derivation of the optimal tax rules</u>

Next consider the optimal tax problem. The problem is to

$$\max_{t,\tau} \quad V(w-t,\tau,a,\phi,G) + f(L) - wL$$

s.t. $tL + \tau(T_c + T_{nc}) = G$

The first order conditions are given by, using Roy's identity and the first order condition for profit maximising behaviour $f' = w$:

$$\begin{aligned} \gamma t\frac{dL}{dt} + (\gamma\tau - MEC)\frac{dT}{dt} &= (1-\gamma)L \\ \gamma t\frac{dL}{d\tau} + (\gamma\tau - MEC)\frac{dT}{d\tau} &= (1-\gamma)T \end{aligned} \tag{A1.6}$$

Here *MEC* is the marginal external cost. It is given by, using the quasi-linearity of preferences and expression (4):

$$MEC = -\frac{\partial V(.)}{\partial a}a' = \alpha T a'; \quad T = T_c + T_{nc} \tag{A1.7}$$

Writing (A1.6) in matrix notation and solving we have:

$$t=\frac{1-\gamma}{\gamma}\left[\frac{L\frac{dT}{d\tau}-T\frac{dT}{dt}}{\frac{dL}{dt}\frac{dT}{d\tau}-\frac{dL}{d\tau}\frac{dT}{dt}}\right]$$
$$\tau=\frac{MEC}{\gamma}+\frac{1-\gamma}{\gamma}\left[\frac{T\frac{dL}{dt}-L\frac{dL}{d\tau}}{\frac{dL}{dt}\frac{dT}{d\tau}-\frac{dL}{d\tau}\frac{dT}{dt}}\right] \tag{A1.8}$$

To derive expressions that are easy to interpret, we work out the total derivatives. We mainly focus on the optimal transport tax rule; a similar approach can be followed for the labour tax. First, note that:

$$\frac{dL}{dt}=\frac{\partial L}{\partial t}+\frac{\partial L}{\partial a}a'\frac{dT}{dt}$$
$$\frac{dL}{d\tau}=\frac{\partial L}{\partial \tau}+\frac{\partial L}{\partial a}a'\frac{dT}{d\tau} \tag{A1.9}$$

To rewrite the total effect of taxes on transport demand is, we start from the definition of total demand as the sum of commuting and non-commuting:

$$T=T\left(w-t,\tau,a,\phi,G\right)=T_c\left(w-t,\tau,a,\phi,G\right)+T_{nc}\left(w-t,\tau,a,\phi,G\right)$$

Differentiating this definition yields:

$$\frac{dT}{dt}=\frac{\partial T}{\partial t}+\frac{\partial T}{\partial a}a'\frac{dT}{dt}$$
$$\frac{dT}{d\tau}=\frac{\partial T}{\partial \tau}+\frac{\partial T}{\partial a}a'\frac{dT}{d\tau}$$

These expressions can be rewritten as:

$$\frac{dT}{dt}=\frac{\partial T}{\partial t}\frac{1}{1-\rho}$$
$$\frac{dT}{d\tau}=\frac{\partial T}{\partial \tau}\frac{1}{1-\rho} \tag{A1.10}$$

where

$$\rho=\frac{\partial T}{\partial a}a' \tag{A1.11}$$

Now first consider the denominator of the final term on the right-hand-side of the optimal tax expressions (A1.8). It can be rewritten as follows, using (A1.9), (A1.10), (A1.11) and (A1.3), and noting that non-commuting demand is independent of the labour tax (see (A1.1) above):

$$\frac{dL}{dt}\frac{dT}{d\tau}-\frac{dL}{d\tau}\frac{dT}{dt}=\frac{1}{1-\rho}\left[\frac{\partial L}{\partial t}\frac{\partial T}{\partial \tau}-\frac{\partial L}{\partial \tau}\frac{\partial T}{\partial t}\right]=\frac{1}{1-\rho}\left[\frac{\partial L}{\partial t}\frac{\partial T}{\partial \tau}-\left(\frac{\partial T_c}{\partial t}\right)^2\right] \qquad \text{(A1.12)}$$

Next look at the numerator in the expression for the optimal transport tax (see (A1.8)). We have:

$$T\frac{dL}{dt}-L\frac{dL}{d\tau}=\left(T\frac{\partial L}{\partial t}-L\frac{\partial L}{\partial \tau}\right)+\frac{\partial L}{\partial a}a'\frac{1}{1-\rho}\left(T\frac{\partial T}{\partial t}-L\frac{\partial T}{\partial \tau}\right)$$

The definition of ρ (see A(1.11)) allows us to rewrite this as:

$$T\frac{dL}{dt}-L\frac{dL}{d\tau}=\frac{1}{1-\rho}\left\{\left(T\frac{\partial L}{\partial t}-L\frac{\partial L}{\partial \tau}\right)+\frac{\partial L}{\partial a}a'\left(T\frac{\partial T}{\partial t}-L\frac{\partial T}{\partial \tau}\right)-\frac{\partial T}{\partial a}a'\left(T\frac{\partial L}{\partial t}-L\frac{\partial L}{\partial \tau}\right)\right\}$$

Using earlier results (in particular (A1.1)-(A1.4)), it follows:

$$\frac{\partial L}{\partial a}=\alpha\frac{\partial L}{\partial \tau};\quad \frac{\partial T}{\partial a}=\alpha\frac{\partial T}{\partial \tau};\quad \frac{\partial L}{\partial \tau}=\frac{\partial T_c}{\partial t}$$

Hence:

$$\frac{\partial L}{\partial a}a'\left(T\frac{\partial T}{\partial t}-L\frac{\partial T}{\partial \tau}\right)-\frac{\partial T}{\partial a}a'\left(T\frac{\partial L}{\partial t}-L\frac{\partial L}{\partial \tau}\right)=-\alpha Ta'\left[\frac{\partial L}{\partial t}\frac{\partial T}{\partial \tau}-\left(\frac{\partial T_c}{\partial t}\right)^2\right]$$

We therefore have:

$$T\frac{dL}{dt}-L\frac{dL}{d\tau}=\frac{1}{1-\rho}\left\{\left(T\frac{\partial L}{\partial t}-L\frac{\partial L}{\partial \tau}\right)-\alpha Ta'\left[\frac{\partial L}{\partial t}\frac{\partial T}{\partial \tau}-\left(\frac{\partial T_c}{\partial t}\right)^2\right]\right\} \qquad \text{(A1.13)}$$

To arrive at the expression used in the text, first, insert (A1.12) and (A1.13) into the tax rule (A1.8) to find:

$$\tau=\frac{MEC}{\gamma}+\frac{1-\gamma}{\gamma}\left[\frac{T\frac{\partial L}{\partial t}-L\frac{\partial L}{\partial \tau}}{\frac{\partial L}{\partial t}\frac{\partial T}{\partial \tau}-\left(\frac{\partial T_c}{\partial t}\right)^2}\right]-\alpha Ta'\left(\frac{1-\gamma}{\gamma}\right) \qquad \text{(A1.14)}$$

Second, use the definition of marginal external cost (see (A1.7)) and note that the definitions of total transport and total labour supply imply:

$$T\frac{\partial L}{\partial t}-L\frac{\partial L}{\partial \tau}=\left(T_c+T_{nc}\right)\left(\frac{\partial T_c}{\partial t}+\phi\frac{\partial H}{\partial t}\right)-(T_c+\phi H)\frac{\partial T_c}{\partial t}=T_{nc}\frac{\partial L}{\partial t}+\phi\left(T_c\frac{\partial H}{\partial t}-H\frac{\partial T_c}{\partial t}\right)$$

Substituting in (A1.14) ultimately yields:

$$\tau = MEC + \left(\frac{1-\gamma}{\gamma}\right)\left[\frac{T_{nc}\frac{\partial L}{\partial t} + \phi\left(T_c\frac{\partial H}{\partial t} - H\frac{\partial T_c}{\partial t}\right)}{\frac{\partial T}{\partial \tau}\frac{\partial L}{\partial t} - \left(\frac{\partial T_c}{\partial t}\right)^2}\right]$$

This is the expression discussed in the paper. Using (A1.10) in (A1.8) yields the optimal labour tax.

Appendix 2: Tax and congestion effects on bargaining outcomes

Tax and congestion effects on bargaining outcomes are derived for both union utility specifications (13) and (14), referred to as bargaining models I and II, respectively.

1. Bargaining model I

Consider the problem:

$$\max_{w,L} \Omega^{\mu}\pi^{1-\mu}\text{, where } \Omega = L(V^e) + (1-L)V^u, \quad \pi = f(L) - wL$$

The two first order conditions are, upon rearrangement (see McDonald and Solow (1981), Creedy and McDonald (1991)):

$$w - f' = V^e - V^u$$
$$w = \mu f / L + (1-\mu) f'$$

The first equation represents the contract curve, the second expression is the Nash curve. Solution gives negotiated wage and employment levels as a function of taxes, congestion and union power.

To evaluate the impact of changes in taxes on labour market outcomes, we differentiate the first-order conditions. Straightforward algebra yields:

$$\frac{\partial w}{\partial t} = (1-\mu) + \frac{\mu}{Lf''}\left(f' - \frac{f}{L}\right)$$
$$\frac{\partial L}{\partial t} = \frac{1}{f''} \qquad \text{(A2.1)}$$

Similarly, the effects of the transport tax τ, of congestion and of telecommuting efficiency on employment and wage are, respectively, given by:

$$\frac{\partial w}{\partial \tau} = \left(T_c^e + T_{nc}^e - T_{nc}^u\right)\left[(1-\mu) + \frac{\mu}{Lf''}\left(f' - \frac{f}{L}\right)\right]$$
$$\frac{\partial L}{\partial \tau} = \frac{T_c^e + T_{nc}^e - T_{nc}^u}{f''} \qquad \text{(A2.2)}$$

$$\frac{\partial w}{\partial a} = \left(\alpha^e\left(T_c^e + T_{nc}^e\right) - \alpha^u T_{nc}^u\right)\left[(1-\mu) + \frac{\mu}{Lf''}\left(f' - \frac{f}{L}\right)\right]$$
$$\frac{\partial L}{\partial a} = \frac{\alpha^e\left(T_c^e + T_{nc}^e\right) - \alpha^u T_{nc}^u}{f''} \tag{A2.3}$$

$$\frac{\partial w}{\partial \phi} = -\frac{\partial V^e}{\partial \phi}\left[(1-\mu) + \frac{\mu}{Lf''}\left(f' - \frac{f}{L}\right)\right]$$
$$\frac{\partial L}{\partial \phi} = -\frac{\partial V^e}{\partial \phi}\frac{1}{f''} \tag{A2.4}$$

Assuming that travel demand of the employed exceeds demand of the unemployed, both labour and congestion taxes have a positive impact on the negotiated wage and reduce the employment level. Exogenous changes in congestion also tend to raise wages under plausible conditions. It suffices that the value of time of the employed is at least as large as for people that do not work and, as before, assuming $T_c^e + T_{nc}^e > T^u$. Finally, telecommuting efficiency reduces wage demands and leads to lower wages and higher employment.

Using (A2.1)-(A2.3) in the general transport tax expression given in the paper (see (16)) we find, after straightforward algebra:

$$\tau = MEC + \left(\frac{1-\gamma}{\gamma}\right)\left[\frac{(1-\rho_t)}{(S)} + \alpha^u a'\right]\left((1-L)T^u\right)$$

2. Bargaining model II

Here the bargaining problem is formulated as:

$$\underset{w,L}{Max}\left(L^\theta \tilde{w}\right)^\mu \left(f - wL\right)^{1-\mu}, \text{ where } \tilde{w} = w - t - \delta\tau - \kappa a$$

First order conditions can be written as:

$$\mu(f - wL) - (1-\mu)L\tilde{w} = 0$$
$$\mu\theta(f - wL) + (1-\mu)L(f' - w) = 0$$

Application of Cramer's rule yields the partial effects:

$$\frac{\partial L}{\partial t} = -\frac{(1-\mu)L^2\left(\mu\theta+(1-\mu)\right)}{N}; \quad \frac{\partial L}{\partial \tau} = -\delta\frac{(1-\mu)L^2\left(\mu\theta+(1-\mu)\right)}{N}$$

$$\frac{\partial L}{\partial a} = -\kappa\frac{(1-\mu)L^2\left(\mu\theta+(1-\mu)\right)}{N}; \quad \frac{\partial L}{\partial \phi} = 0$$

$$\frac{\partial w}{\partial t} = -\frac{(1-\mu)L\left[(1-\mu)Lf''-(w-f')(\mu\theta+(1-\mu))\right]}{N}$$

$$\frac{\partial w}{\partial \tau} = -\delta\frac{(1-\mu)L\left[(1-\mu)Lf''-(w-f')(\mu\theta+(1-\mu))\right]}{N} \tag{A2.5}$$

$$\frac{\partial w}{\partial a} = -\kappa\frac{(1-\mu)L\left[(1-\mu)Lf''-(w-f')(\mu\theta+(1-\mu))\right]}{N}$$

$$\frac{\partial w}{\partial \phi} = 0$$

where $N = (w-f')\left(\mu\theta+1-2\mu-\frac{1-\mu}{\theta}\right)-Lf''>0$ by concavity and the second order conditions. It is then unambiguously clear that

$$\frac{\partial L}{\partial t}, \frac{\partial L}{\partial \tau}, \frac{\partial L}{\partial a} < 0$$

$$\frac{\partial w}{\partial t}, \frac{\partial w}{\partial \tau}, \frac{\partial w}{\partial a} > 0$$

Telecommuting efficiency has no effect on the negotiated outcomes, given the specification of union utility.

Using (A2.5) in expression (16) yields, after slight manipulations:

$$\tau = MEC + \left\{\frac{(1-\gamma)}{\gamma}\frac{(1-\rho_t)}{[S]}\right\}\left[T-L\delta\right]+\left[\frac{1-\gamma}{\gamma}\right]\left\{MEC-L\kappa a'\right\}$$